mercury bioaccumulating in fish and wildlife. Therefore, the proposed water quality objectives and Implementation Plan will protect all beneficial uses of the marsh and will not degrade the quality of the environment, substantially reduce fish or wildlife habitat, cause fish or wildlife population to drop below self-sustaining levels or threaten to eliminate a plant or animal community.

Moreover, the TMDL's monitoring provisions and the Water Board's adaptive management approach to implementation provide additional safeguards and guarantees that future implementation of the Basin Plan amendment will be carried out in ways that enhance, and do not degrade, the quality of the environment in the marsh.

Furthermore, the project does not have impacts that are individually limited, but cumulatively considerable. In fact, coordination of implementation of BMPs among multiple duck clubs will reduce, rather than increase, the impacts of low dissolved oxygen.

The Basin Plan amendment will not adversely affect people, either directly or indirectly. To the contrary, achievement of water quality objectives is expected to support healthy fish populations, reduce bioaccumulation of mercury in sportfish, and enhance aesthetic attributes and recreational opportunities within the marsh sloughs. All of these effects will benefit people using the marsh for recreation orr subsistence directly.

14.3.3 Potential Cumulative Impacts

This Basin Plan amendment is specifically designed to improve DO conditions and envance habitat values and beneficial uses in the marsh sloughs. The cumulative impact here is the overall positive change in the environment from coordinated actions to improve water quality in the marsh. As shown in the Environmental Checklist, there are no potentially significant environmental impacts from the implementation of this Basin Plan amendment, and the project is consistent with the SMP and its programmatic EIS/EIR (SMP 2014), where the regional and cumulative impacts have already been adequately addressed.

For this reason, the adoption of the Basin Plan amendment does not require further evaluation of cumulative effects.

14.4. CONSIDERATION OF ALTERNATIVES

As explained in this report, the proposed project would not result in any significant adverse impacts on the environment and would not cause any reasonably foreseeable indirect physical changes; therefore, alternatives beyond the No Project alternative are not explored.

Though an alternative analysis is not needed to lessen or mitigate impacts, we provide a discussion of the No Project alternative to illustrate that the proposed project would be environmentally beneficial.

Alternative: No Project

Under this alternative, the Water Board would not amend the Basin Plan to establish the following: revised water quality objectives for DO in Suisun Marsh sloughs, a TMDL designed to achieve these objectives, and an Implementation Plan. The purpose of the TMDL is to achieve DO objectives, prevent fish kills and reduce occurrences of anthropogenically induced low DO in Suisun Marsh sloughs, thereby protecting beneficial uses of these waterbodies. The No Project alternative would not meet the project objective to update the Basin Plan to incorporate the site-specific water quality objectives for DO representing the best available scientific information. Nor would it increase the likelihood of water quality protection or restoration of the impaired beneficial uses in Suisun Marsh sloughs. The inaccuracies in the existing DO objectives would not be corrected, and fish kills might continue to occur.

The implementation would also be limited to actions from responsible parties engaged in land use activities that are currently covered by State or Regional Water Board permits. The No Project approach would potentially allow some dischargers to continue to engage in activities that discharge low DO waters without a regulatory oversight, which, in turn, will likely result in the non-attainment of water quality standards. In addition, federal and state implementation grants and other funding sources are typically only available for projects located in watersheds that have an approved TMDL or some other effective watershed-scale management plan in place.

The No Project alternative would not set targets, and it would not ensure that monitoring would continue to demonstrate the achievement of those targets. It would potentially result in economic impacts of unnecessary enforcement, or lead to significant burden of developing a large number (over a hundred) of individual permits to help control water quality in the sloughs.

Thus, the No Project alternative would not meet the objective to ensure ongoing protection of existing water quality, prevent fish kills or low DO induced recruitment impacts to aquatic organisms in Suisun Marsh.

Preferred Alternative

The proposed Basin Plan amendment meets all the project objectives and will not result in any significant adverse environmental impacts. The alternative does not meet all the project objectives and is not environmentally superior. Therefore, the proposed Basin Plan amendment is the preferred alternative.

15. REFERENCES

Alpers, C., C. Eagles-Smith, C. Foe, S. Klasing, M. Marvin-DiPasquale, D. Slotton, and L. Windham-Myers. 2008. Sacramento-San Joaquin Delta Regional Ecosystem Restoration Implementation Plan. Ecosystem *Conceptual Model Mercury*. https://pubs.er.usgs.gov/publication/70176654

Alpers, C., M.P. Huneralch, J.T. May, and R.L. Hothem. 2005. *Mercury Contamination from Historical Gold Mining in California*. USGS Fact Sheet 2005–3014. https://pubs.usgs.gov/fs/2005/3014/.

Bachand, P.A.M., S.W. Siegel, D. Gillenwater, J. Fleck, B. Bergamaschi, W. Horwath. 2010. *The water quality of managed wetlands studied in the Suisun low DO and MeHg project, Suisun Marsh. Appendix C Water Quality* in Siegel et al. 2011.

Bailey, H., C. Curran, S. Poucher, and M. Sutula. 2014. *Science Supporting Dissolved Oxygen Objectives for Suisun Marsh*. SCCWRP Report 830, March 10, 2014.

Bricker, S., B.Longstaff, W.Dennison, A.Jones, K.Boicourt, C.Wicks, and J. Woerner. 2007. *Effects of Nutrient Enrichment In the Nation's Estuaries: A Decade of Change.* NOAA Coastal Ocean Program Decision Analysis. Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD. Chapter 2: 9–20.

Campbell, J.G. and L.R. Goodman. 2004. Acute sensitivity of juvenile Shortnose Sturgeon to low dissolved oxygen concentrations. EPA/600/J-04/175. Trans. Am. Fish. Soc. 133(3):772–776.

CDHS & SFEI (California Department of Health Services and San Francisco Estuary Institute). 2000. *San Francisco Bay Seafood Consumption Report.* Technical Report, pp. 41 to 42, 51 to 57, and 60, Appendix E, and Appendix K (Table K30a).

Crain, P. and P. Moyle, 2011. Appendix D. Aquatic Ecology In: Siegel et al, 2011a, *Final Evaluation Memorandum Strategy for Resolving MeHg and Low Dissolved Oxygen Events in Northern Suisun Marsh.*. State Water Resources Project Number 06-283-552-0. May 2011.

Davis, J.A., M.D. May, G. Ichikawa, and D. Crane. 2000a. *Contaminant Concentrations in Fish from the Sacramento-San Joaquin Delta and Lower San Joaquin River 1998.* San Francisco Estuary Institute, Richmond, CA.

Davis, J.A., L.J. McKee, J.E. Leatherbarrow, and T.H. Daum. 2000b. *Contaminant Loads from Stormwater to Coastal Waters in the San Francisco Bay Region.* Comparison to other pathways and recommended approach for future evaluation. San Francisco Estuary Institute, Richmond, CA.

Davis, J.A., K. Abu-Saba, A.J. Gunther. 2001. *Technical Report of the Sources, Pathways and Loadings Workgroup*. San Francisco Estuary Institute, Richmond, CA. March 2001. Available at: http://www.sfei.org/sites/default/files/biblio_files/splwg_finalv2.pdf

Davis, J.A., D. Yee, J.N. Collins ,S.E. Schwarzbach, and S.N. Luoma. 2003. Potential for increased mercury accumulation in the estuary food web. San Francisco Estuary and Watershed Science [online serial]. Vol 1, Issue 1 (October 2003), Article 4. http://escholarship.org/uc/item/9fm1z1zb

Davis, J.A., B.K. Greenfield, G. Ichikawa, and M. Stephenson. 2008. Mercury in sport fish from the Sacramento-San Joaquin Delta region, California, USA. Science of the Total Environment 391: 66–75.

Davis, J.A., R.E. Looker, D. Yee, M.M-Di. Pasquale, J.L. Grenier, C.M. Austin, L.J. McKee, B.K. Greenfield, R. Brodberg, and J.D. Blum. 2012. Reducing methylmercury accumulation in the food webs of San Francisco Bay and its local watersheds. Environmental Research 119: 3–26.

Decker, M.B., D.L. Breitburg, and N. H. Marcus. 2003. Geographical differences in behavioral responses to hypoxia: Local adaptation to an anthropogenic stressor? Ecological Applications 13:1104–1109.

DFG (Department of Fish and Game). 2010. *Conceptual Model for Managed Wetlands in Suisun Marsh.* Compiled by DFG and SRCD.

DFG (Department of Fish and Game). 2008. *Ecosystem Restoration Program (ERP) Conservation Strategy for Stage 2 Implementation*. Sacramento-San Joaquin Delta and Suisun Marsh and Bay Planning Area.

DWR (Department of Water Resources). 2001. *Comprehensive Review Suisun Marsh Monitoring Data 1985–1995*. Submitted in fulfillment of Suisun Marsh Preservation Agreement and Suisun Marsh Monitoring Agreement.

DWR (Department of Water Resources). 2007. *Mercury Water Quality Conceptual Model*. https://www.fws.gov/sacramento/outreach/2010/10-29/Documents/Mercury_Water_Quality_Conceptual_Model.pdf

Downing, B.D., B.A. Bergamaschi, T.E.C. Kraus, E. Beaulieu and F. Anderson. 2010. *Appendix F: Suisun Marsh Dissolved Organic Matter* in Siegel et al. 2011.

Eby, L.A., L.B. Crowder, C.M. McClellan, C.H. Peterson and M.J. Powers. 2005. Habitat degradation from intermittent hypoxia: impacts on demersal fishes. Marine Ecology-Progress Series 291: 249–261.

Enright, C., C. Enos, A. Mueller, and B.A. Bergamaschi. 2009. Suisun Marsh Water Quality: Mercury, Organic Matter, and Scalar Transport.

Fisher, J., and M.C. Acreman. 2004. Wetland nutrient removal: a review of the evidence. Hydrology and Earth System Sciences 8(4): 673–685.

FDEP (Florida Department of Environmental Protection). 2013. Technical Support Document: *Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters*. DEP-SAS-001/13. Chapter 1: 1–12.

Geiser, L.H., S.E. Jovan, D.A. Glavich, and M.K. Porter. 2010. Lichen-based critical loads for atmospheric nitrogen deposition in Western Oregon and Washington Forests, USA. Environmental Pollution 158: 2412–2421.

Gill, G. 2008. Calfed Mercury Project Task 3 - *Atmospheric Mercury Deposition Studies*. Available at: https://mercury.mlml.calstate.edu/wp-content/uploads/2008/10/06_task3_final.pdf

Gillenwater, D., S. Siegel, J. Schlueter, P.Bachand, K. Summers, and S. Roy. 2013. *Best Management Practice Recommendations*. Suisun Marsh TMDL Development Memorandum. January 2013. Available at: http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/suisunmarsh/Suisun%20Marsh%20TMDL%20BMP%20Recommendations.pdf

Gilmour, C. C., E. A. Henry, and R. Mitchell. 1992. Sulfate stimulation of mercury methylation in freshwater sediments. Environmental Science and Technology 26: 2281–2287.

Greenfield, B., K.Ridolfi, and K.Harrold. 2009. *Mercury concentrations and isotopes in San Francisco Bay forage fish*. Presentation at the 2009 RMP Annual Meeting.

Grenier, L., B.Greenfield, D.Slotton, and S.Ayers. 2010. *North Bay Small Fish Mercury Monitoring with a Focus on Napa-Sonoma Managed Ponds and Sloughs V.2*. Contribution No. 620. Aquatic Science Center, Oakland, California.

Heim, W.A., K. Coale, and M. Stephenson. 2003. *Methyl and total mercury spatial and temporal trends in surficial sediments of the San Francisco Bay-Delta*. Assessment of Ecological and Human Health Impacts of Mercury in the Bay –Delta Watershed. CALFED Bay-Delta Mercury Project Final Report.

Heim, W.A, Coale, K.H., Stephenson, M., Choe, K.-Y., Gill, G.A, and C. Foe. 2007. Spatial and habitat-based variations in total and methyl mercury concentrations in surficial sediments in the San Francisco Bay-Delta. Environmental Science and Technology 41, 3501–3507.

Heim, W.A., M. Stephenson, B. Hughes, A. Bonnema, and K. Coale. 2008. *Task 5.3a Methylmercury Loading Studies in Delta Wetlands: Sycamore Slough and Suisun Marsh*. CALFED Mercury Project Report.

Hurley, J.P., J.M. Benoit, C.L. Babiarz, M.M. Shafer, A.W. Andren, J.R. Sullivan. 1995. Influences of Watershed Characteristics on Mercury Levels in Wisconsin Rivers. Environmental Science and Technology 29: 1867–1875.

Kelly, CA, JWM. Rudd, RA. Bodaly, N.P. Roulet, V.L. St.Louis, A. Heyes, T.R. Moore, S. Schiff, R. Aravena, K.J. Scott, KJ., B. Dyck, R. Harris, B. Warner, and G. Edwards. 1997. Increases in fluxes of greenhouse gases and methyl mercury following flooding of an experimental reservoir. Environmental Science and Technology 31:1334–1344.

Louie, S., C. Foe, and D. Bosworth. 2008. *Task 2 Mercury and Suspended Sediment Concentrations and Loads in the Central Valley and Freshwater Delta.* https://mercury.mlml.calstate.edu/wp-content/uploads/2008/10/05_task2thg_final.pdf

Marvin-DiPasquale M.C., J.L. Agee, R.M. Bouse, and B.A. Jaffe. 2003. Microbial cycling of mercury in contaminated and wetland sediments of san Pablo Bay, California. Environmental Geology 43: 260–267.

Marvin-DiPasquale, M., and M.H. Cox. 2007. Legacy mercury in Alviso Slough, South San Francisco Bay, California: Concentration, speciation and mobility. U.S. Geological Survey, Open-File Report 2007–1240, 98p.

McKee, L.J., Sutula, Gilbreath, A.N., Beagle, J., Gluchowski, D., and Hunt, J. 2011 *Numeric nutrient endpoint development for San Francisco Bay- Literature review and Data Gaps Analysis.* Southern California Coastal Water Research Project Technical Report No. 644. http://www.sccwrp.org/.

Melwani, A.R., B.K. Greenfield, D. Yee, and J.A. Davis. 2012. *Conceptual Foundations for Modeling Bioaccumulation in San Francisco Bay.* SFEI Contribution #676. San Francisco Estuary Institute, Richmond, CA.

Mueller-Solger, A., and B. Bergamaschi. 2005. *Conceptual Model: Organic Matter in Suisun Marsh.* https://www.fws.gov/sacramento/outreach/2010/10-29/Documents/Organic_Matter_Conceptual_Model.pdf

NMFS (National Marine Fisheries Service). 2013. *NMFS Biological Opinion on the proposed 30-year Suisun Marsh Habitat Management, Preservation, and Restoration Plan.*

O'Rear, T.A., and P.B. Moyle. 2015. *Trends in Fish Populations of Suisun Marsh January 2014 – December 2014.* Center for Watershed Sciences. UC. Davis.

O'Rear, T.A., and P.B. Moyle. 2010. *Trends in Fish Populations of Suisun Marsh January 2009 – December 2009.* Center for Watershed Sciences. UC. Davis.

Parker, A.E., M.C. Ferner, and E. Ceballos. 2015. *Initial Recommendations Regarding the Potential for Nutrient Impairment of Ecosystem Health in Suisun Marsh, CA.* A Report for the San Francisco Regional Water Quality Control Board (Region II). Agreement Number 12-135-250, 12 June 2015.

Raymond, P. A. and J.E. Bauer. 2001. DOC cycling in a temperate estuary: A mass balance approach using natural 14C and 13C isotopes. Limnology and Oceanography 46(3): 655–667.

Rudd, J.W.M. 1995. Sources of methylmercury to freshwater ecosystems. A review. Water Air and Soil Pollution 80: 697–713.

SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2006. Mercury in San Francisco Bay Proposed Basin Plan Amendment and Staff Report for Revised Total Maximum Daily Load (TMDL) and Proposed Mercury Water Quality Objectives. August 1, 2006.

SFEI (San Francisco Estuary Institute). 2015. *The Pulse of the Bay: The State of the Bay Water Quality, 2015 and 2065*. SFEI Contribution #759, page 35. San Francisco Estuary Institute, Richmond, CA.

Schroeter, R.E., and P.B. Moyle. 2001. *Trends in Fish Populations of Suisun Marsh: January 2000 – December 2000*. Annual Report to California Department of Water Resources.

Schroeter, R.E. and P.B. Moyle. 2003. *Trends in Fish Population of Suisun Marsh: January 2002- December 2002*. Annual Report to California Department of Water Resources.

Schroeter, R.E., and P.B. Moyle. 2004. *Dissolved Oxygen Sags in Suisun Marsh, 2004*. Annual Report to California Department of Water Resources.

Seitz, R.D., D.M. Dauer, R.J. Llansó, and W.C. Long. 2009. Broad-scale effects of hypoxia on benthic community structure in Chesapeake Bay, USA. Journal of Experimental Marine Biology and Ecology 381: S4–S12.

Siegel, S., P. Bachand, D. Gillenwater, S. Chappell, B. Wickland, O.Rocha, M. Stephenson, W. Heim, C. Enright, P. Moyle, P.Crain, B. Downing, B. Bergamaschi. 2011. Final evaluation memorandum, *Strategies for resolving low dissolved oxygen and methylmercury events in northern Suisun Marsh*. Prepared for the State Water Resources Control Board, Sacramento, California. SWRCB Project Number 06-283-552-0.

Slotton, D., 2008. The UC Davis Biosentinel Mercury Program (Fact Sheet). *Using Small Fish to Monitor Fine-scale Patterns of Methylmercury Contamination in the Watershed*. Contribution No.552 May 2008. (Silversides Fish Data Set for Suisun Marsh and Bay Region).

Slotton, D.G., S.M. Ayers, T.H. Suchanek, R.D. Weyand, A.M. Liston, C. Asher, D.C. Nelson, and B. Johnson. 2002. *The Effects of Wetland Restoration on the Production and Bioaccumulation of Methyl mercury in the Sacramento- San Joaquin Delta, California*. CALFED Bay-Delta Program Draft Report. 49p. Available at: http://loer.tamug.edu/calfed/Report/DraftFinal/UCD_Delta_Report.pdf

Sobczak, W.V. J.E. Cloern, A.D. Jassby, and A.B. Muller-Solger. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proceedings of the National Academy of Sciences 99 (12): 8101–8105.

St. Louis, V.L., J.W.M. Rudd, C.A. Kelly, K.G. Beaty, N.S. Bloom, and R.J. Flett. 1994. Importance of wetlands as sources of methyl mercury to boreal forest ecosystems. Canadian Journal of Fishery and Aquatic Science 51: 1065–1076.

Stephen, C.E., D.I. Mount, D.J. Hansen, J.R. Gentile, G.A. Chapman, and W.A. Brungs. 1985. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*. PB85-227049. Office of Research and Development.

Stephenson M., Bonnema, A., Heim, W. and K.H. Coale. 2010. *Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries: An Integrated Mass Balance Assessment Approach*. **Task 5.3a.** Methylmercury Loading Studies in Delta Wetlands – Grizzly Island.

Stover, A., R. Schroeter, and P.B. Moyle. 2004. Trends in fish populations of Suisun Marsh January 2004- December 2004. Prepared for California Department of Water Resources. Contract SAP 4600001964.

SMPP. 1976. *Suisun Marsh Protection Plan*. http://www.bcdc.ca.gov/plans/suisun_marsh#3

SMP. 2014. *Suisun Marsh Habitat Management, Preservation, and Restoration Plan*. Executive Summary. Final Environmental Impact Statement/Environmental Impact Report (https://www.usbr.gov/mp/nepa/documentShow.cfm?Doc_ID=8681)

Sutula, M., H. Bailey, and S. Poucher. 2012. *Science Supporting Dissolved Oxygen Objectives in California Estuaries*. Southern California Coastal Water Research Project Technical Report No. 684. http://www.sccwrp.org/. December 2012.

Tetra Tech, Inc. 2017. *DO Criteria Recommendations for Suisun Marsh*. Final Report. June 15, 2017. Revised October 23, 2017.

Tetra Tech, Inc. 2013a. *Suisun Marsh Conceptual Model/Impairment Assessment Report for Organic Enrichment, Dissolved Oxygen, Mercury, Salinity and Nutrients*. Draft Report. Prepared for US EPA Region IX and the San Francisco Bay Regional Water Board.

Tetra Tech, Inc. 2013b. *Restoring Areas of Suisun Marsh to Tidal Wetlands: Potential Effects on Mercury Geochemical Interactions and Implications for the Suisun Marsh TMDL*. Prepared for US EPA Region IX and the San Francisco Bay Regional Water Board.

USBR (U.S. Bureau of Reclamation). 2011. *Suisun Marsh Habitat Management, Preservation, and Restoration Plan Final EIS/EIR, Chapter 6, Biological Environment*. On the Internet at: http://www.usbr.gov/mp/nepa/documentShow.cfm?doc_id=8700.

USEPA (U.S. Environmental Protection Agency). 2008. *Methods for Evaluating Wetland Condition* #18 Biogeochemical Indicators. Office of Water. EPA-822-R-08-022.

USEPA (U.S. Environmental Protection Agency). 2003. Appendix B-Sensitivity to Low Dissolved Oxygen Concentrations for Northern and Southern Atlantic Coast Populations of Selected Test Species in *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and its Tidal Tributaries*. Office of Water. EPA-903-R-03-002.

USEPA (U.S. Environmental Protection Agency). 2001. *Water Quality Criterion for the Protection of Human Health: Methylmercury*, EPA-823-R-01-001. Washington, D.C.: Office of Water, pp. xiv, 5-56–5-59, 7-1–7-2.

USEPA (U.S. Environmental Protection Agency). 2000. *Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras*. EPA-822-R-00-012. Washington, D.C.: Office of Water.

USEPA (U.S. Environmental Protection Agency). 1985. Ambient Water Quality Criteria for Mercury – 1984. EPA 440/5-84-026. Washington, D.C.: Office of Water, pp. 23, 24, 47.

USFWS (U.S. Fish and Wildlife Service). 2003. *Evaluation of the Clean Water Act Section 304(a) Human Health Criterion for Methylmercury: Protectiveness for Threatened and Endangered Wildlife in California*. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Environmental Contaminants Division. October 2003.

Vaquer-Sunyer, R. and C. M. Duarte. 2008. Thresholds of hypoxia for marine biodiversity. Proceedings of the National Academy of Sciences 105 (40):15452-15457.

Vymazal, J. 2007. Removal of nutrients in various types of constructed wetlands. Science of the Total Environment 380: 48–65.

Wiener, J.G., C.C. Gilmour, and D.P. Krabenhoft. 2003. *Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration*. Draft Final Report to CALFED. February 28, 2003.

Yee, D., J. Collins, L. Grenier, J. Takekawa, D. Tsao-Melcer, I. Woo, S. Schwarzbach, M. Marvin-DiPasquale, L. Windham, D. Krabbenhoft, S. Olund and J. DeWild. 2008. *Mercury and Methylmercury Processes in North San Francisco Bay Tidal Wetland Ecosystems*. CalFed ERP02D-P62 Final Report. Submitted to California Bay-Delta Authority Ecosystem Restoration Program. SFEI Contribution #621. San Francisco Estuary Institute, Oakland, CA.
http://www.sfei.org/sites/default/files/biblio_files/Yee%20et%20al%20-%20Petaluma%20R.%20-%20CalFed%20ERP02D-P62%20Final%20Report%202008.pdf

Yee, D., L.J. McKee, and J.J. Oram. 2011. A regional mass balance of methylmercury in San Francisco Bay, California, USA. Environmental Toxicology and Chemistry 30(1): 88–96.

Yu, R.-Q., J. R. Flanders, E.E. MacK, R. Turner, M.B. Mirza, and T. Barkay. 2012. Contribution of coexisting sulfate and iron reducing bacteria to methylmercury production in freshwater river sediments. Environmental Science and Technology 46(5): 2684–2691.

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Appendix A: Summary of Data Used in the Report

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1. DO Concentrations in Suisun Marsh								
Site	**Location**	**Record Period**	**Frequency**	**Mean**	**SD**	**Min**	**Max**	**Source**
NZ032	Montezuma Slough, 2nd bend from mouth	1999–2007	Monthly	8.30	0.89	6.7	11.2	P. Moyle
MZ1	Montezuma Slough at Roaring	2000–2011	Monthly	4.34	3.55	0.1	13.8	P. Moyle
MZ2	Montezuma Slough at boat ramp	2000–2011	Monthly	4.47	3.51	0.1	13.55	P. Moyle
SU1	Suisun Slough seining beach	2000–2011	Monthly	4.28	3.75	0.3	75.9	P. Moyle
SU2	Suisun Slough- below Boynton Slough	2000–2011	Monthly	4.43	2.75	0.1	11	P. Moyle
SU3	Suisun Slough – above Cordelia Slough	2000–2011	Monthly	6.24	3.51	0.2	13.9	P. Moyle
SU4	Suisun Slough – below Cordelia Slough	2000–2011	Monthly	6.4	3.6	0.2	14.8	P. Moyle
S42	Suisun Slough 300' south of Volanti Slough	1978–1985	Monthly	7.90	0.82	5.6	10	P. Moyle
GY1	Goodyear Slough – upper	2000–2011	Monthly	6.21	3	0.1	16	P. Moyle
GY2	Goodyear Slough - middle	2000–2011	Monthly	6.19	3.02	0.1	14	P. Moyle
GY3	Goodyear Slough – lower	2000–2011	Monthly	6.19	3.42	0.1	13.5	P. Moyle
BY1	Boynton Slough - upper	2000–2011	Monthly	3.29	2.53	0.1	11.2	P. Moyle
BY3	Boynton Slough – lower	2000–2011	Monthly	3.81	2.62	0.1	10.2	P. Moyle
PT1	Peytonia Slough – upper	2000–2011	Monthly	3.46	2.65	0.1	10.5	P. Moyle
PT2	Peytonia Slough – middle	2000–2011	Monthly	3.75	2.67	0.1	10.64	P. Moyle
CO1	Cutoff Slough –site 1	2000–2011	Monthly	7.38	1.36	4.30	10.90	P. Moyle
CO2	Cutoff Slough – site 2	2000–2011	Monthly	7.52	1.35	4.50	12.75	P. Moyle
DV2	Denverton Slough – middle	2000–2011	Monthly	7.13	1.54	3.50	11.80	P. Moyle
DV3	Denverton Slough - lower	2000–2011	Monthly	7.16	1.35	3.40	11.50	P. Moyle
NS2	Nurse Slough – middle	2000–2011	Monthly	7.90	1.37	3.50	11.80	P. Moyle
NS3	Nurse Slough – lower	2000–2011	Monthly	8.08	1.37	3.70	13.00	P. Moyle
SB1	Spring Branch – upper	2000–2011	Monthly	6.78	1.44	0.62	10.60	P. Moyle
SB2	Spring Branch – middle	2000–2011	Monthly	6.91	1.28	1.40	10.36	P. Moyle

2. FSSD Receiving Water Data					
Station	**Location**	**Record Period**	**Frequency**	**Parameters**	**Source**
C-1(RW1)	Boynton Slough, about 100 feet downstream from the discharge outfall	2005–2010	Seasonal	Temperature, DO, pH, secchi disk, salinity, turbidity, PO4, NO3, TKN, NH3, unionized NH3, organic N, chlorophyll a	FSSD receiving water study
C-2 (RW2)	Boynton Slough, about 100 feet downstream from Southern Pacific Railroad crossing	2005–2010	Seasonal		FSSD receiving water study
C-3 (RW3)	Boynton Slough, 1800 feet downstream from discharge outfall	2005–2010	Seasonal		FSSD receiving water study
C-4 (RW4)	Boynton Slough, in the mouth where it enters Suisun Slough	2005–2010	Seasonal		FSSD receiving water study
C-5 (RW5)	Mouth of Sheldrake Slough as it enters Suisun Slough	2005–2010	Seasonal		FSSD receiving water study
C-6 (RW6)	Peytonia Slough, in the mouth where it enters Suisun Slough	2005–2010	Seasonal		FSSD receiving water study
CR1 (RW7)	Peytonia Slough, about 100 feet downstream from railroad crossing	2005–2010	Seasonal		FSSD receiving water study
CR2 (RW8)	Chadbourne Slough, about 100 feet downstream from railroad crossing	2005–2010	Seasonal		FSSD receiving water study

3. Intensive DO monitoring in Sloughs					
Station	**Location**	**Record Period**	**Frequency**	**Parameters**	
PS-CWQ-1	Peytonia Slough	09/07–12/08	15 min	Intensive (15min) DO monitoring data	Siegel et al. 2011
BS-CWQ	Boynton Slough	09/07–12/08	15 min	Intensive (15min) DO monitoring data	Siegel et al. 2011
	Goodyear Slough	08/12–02/13	15 min	DO, temperature, specific conductivity, pH	Regional Water Board, 2013
	Denverton Slough	08/12–02/13	15 min	DO, temperature, specific conductivity, pH	Regional Water Board, 2013
	First Mallard Slough	05/08 – 05/14	15 min	DO	NOAA NERRS
	Second Mallard Slough	05/08-05/14	15 min	DO	NOAA NERRS

Appendix B: Assessment of Water Quality Data: Dissolved Oxygen and Nutrients

Prepared by Tetra Tech Inc., 2015

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Assessment of Water Quality Data: Dissolved Oxygen and Nutrients - *Prepared by Tetra Tech Inc., 2015*

DISSOLVED OXYGEN

Dissolved oxygen (DO) concentrations across Suisun Marsh are compared to the existing Basin Plan water quality objectives (Table B-1). For the present evaluation, larger sloughs in Suisun Marsh could be considered as tidal waters upstream of Carquinez Strait, and, therefore, the currently-applicable water quality standard for DO in the Basin Plan is 7 mg/L. However, it is recognized that the specific water quality impairments occur not in large, tidally-mixed open-water areas, but in small, poorly-mixed slough channels. The latter may require a different DO target, reflecting the natural mixing characteristics of these waters and their beneficial uses. An alternative DO target may be developed by evaluating reference sloughs with contributing watersheds in relatively natural conditions, and by evaluating the physiological requirements of organisms that are present in Suisun Marsh. This document presents an overview of DO levels in minimally impacted sloughs for comparison against all other locations in Suisun Marsh. Additional work, not presented here, is being performed by the Water Board to better define the DO requirements from a physiological standpoint. Together, both the reference and physiological approaches, as well the current Basin Plan requirements, will be used to define future DO targets for Suisun Marsh.

Table B-1
Existing Basin Plan water quality objectives for dissolved oxygen

Tidal Waters	DO [mg/L]	DO [% saturation][1]
Downstream of Carquinez Bridge	5.0 mg/L minimum	80%
Upstream of Carquinez Bridge (Suisun Marsh)	7. 0 mg/L minimum	80%

[1] median dissolved oxygen concentration for any three consecutive months

Dissolved Oxygen at Grab Sample Locations

Observed DO data were mainly collected by UC Davis in the fish study (P. Moyle, personal communication) and by the Bay Area Delta and Tributaries system compliance monitoring at stations in Montezuma Slough, Suisun Slough, Goodyear Slough, Boynton Slough, and Peytonia Slough. Locations of these monitoring stations are shown in Figure B-1.

DO concentrations observed at stations in Montezuma Slough are meeting the water quality objective of 7 mg/L most of the time, with only a few exceptions (about 8% of the time). Percent dissolved oxygen saturation in Montezuma Slough is occasionally lower than the 80% saturation (for about 20% of the time; Figure B-2; Table B-2). When compared to the 80% saturation criterion, a median value over every three-month period was calculated based on the bi-weekly data. Three stations in Suisun Slough (SU3, SU4, and SU42) showed DO concentrations above the criterion of 7 mg/L most of the time (Table B-2). DO concentrations in the upper reach of Suisun Slough (SU1 and SU2 below Boynton Slough) were below 7 mg/L nearly half of the time and were largely below the saturation objective (in excess of 80% of measurements) (Figure B-3). Percent DO saturation at SU3 and SU4 was mostly above 80% saturation with only a few exceptions.

DO concentrations measured at tributary sloughs showed exceedances of DO objectives for a significant percent of time, particularly in the upper and middle sections of Goodyear Slough (Figure B-4). Low DO concentrations usually occurred in late summer and fall months.

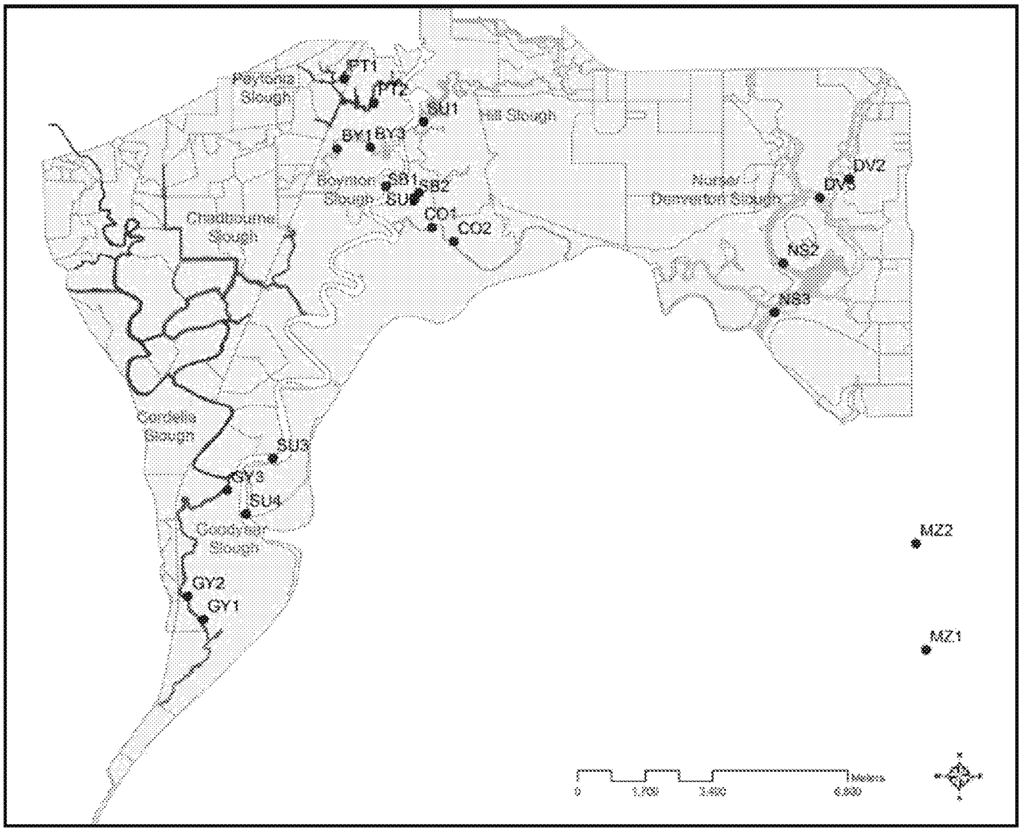
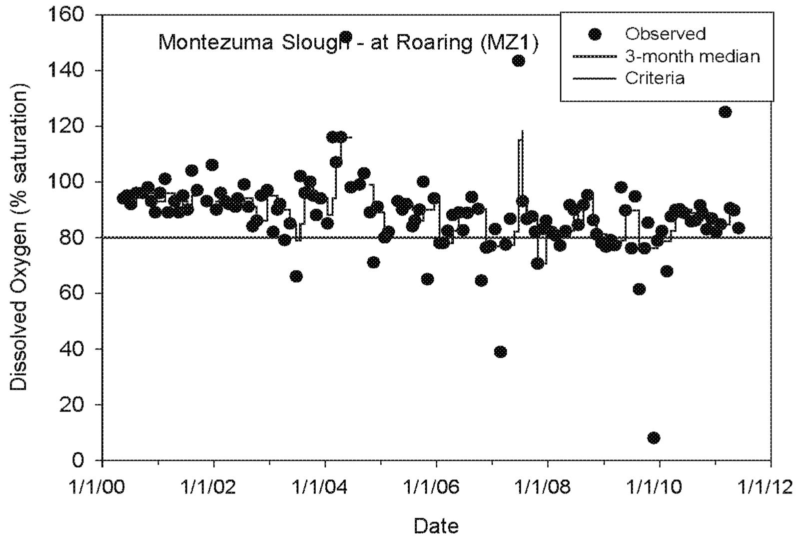


Figure B-1 Monitoring locations for DO, salinity and specific conductance

PT: Peytonia Slough, BY: Boynton Slough, GY: Goodyear Slough, CO: Cutoff Slough, SB: First Mallard, DV: Denverton Slough, NS: Nurse Slough, MZ: Montezuma Slough, SU: Suisun Slough



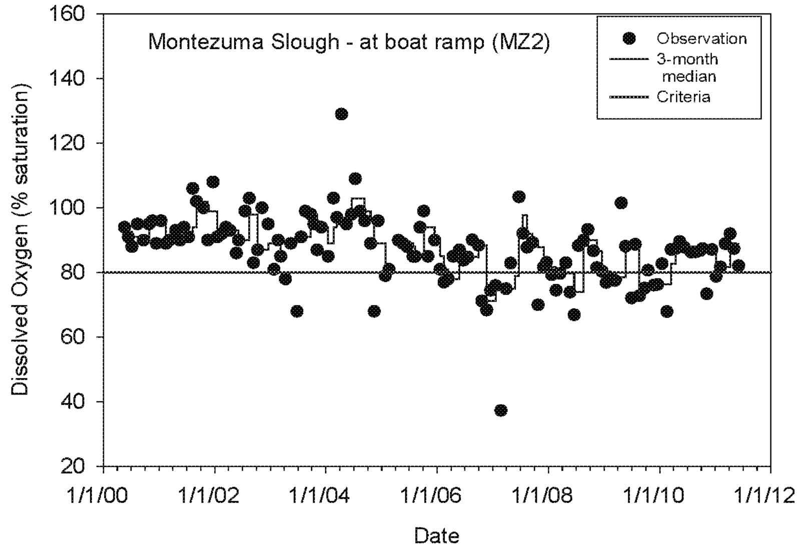


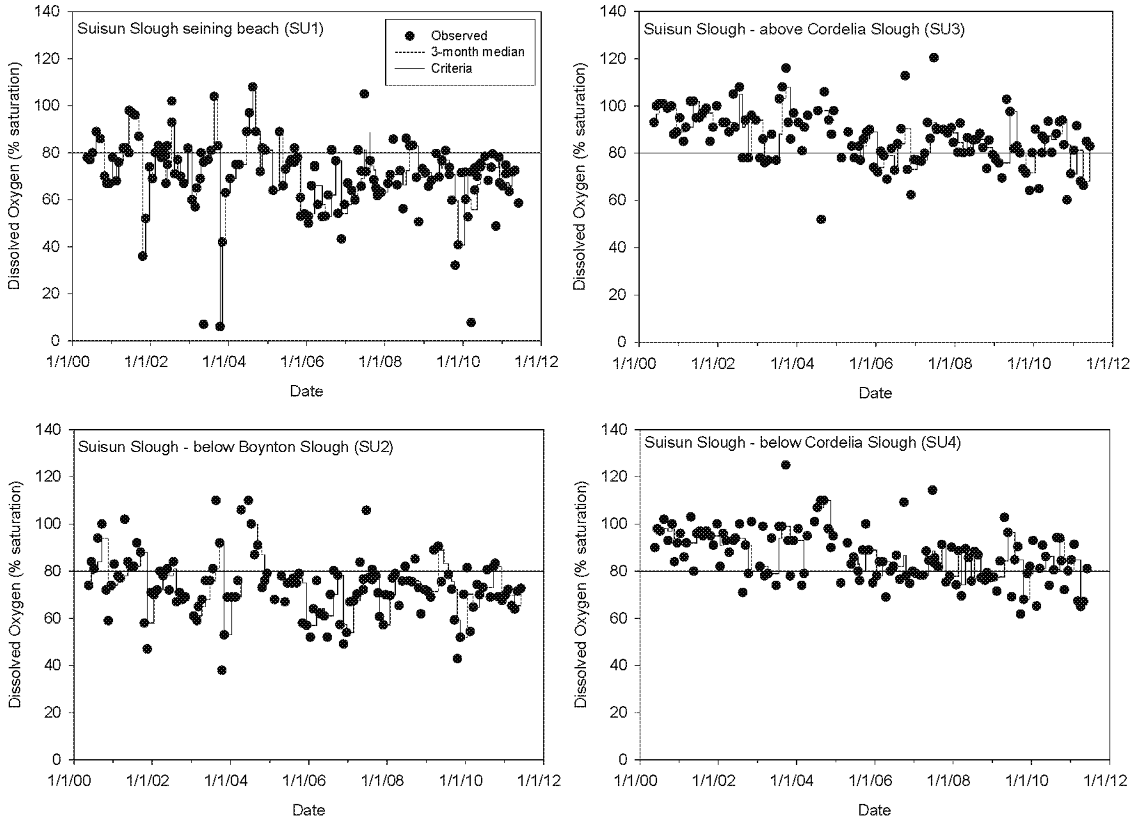
Figure B-2 Percent DO saturation measured at Montezuma Slough

(Sites MZ1 and MZ2 - Source: BDAT Project; Moyle, personal communication)

Table B-2
Stations with DO concentrations in Suisun Marsh

Site	Location	Record Period	% of Samples Below 7 mg/L	% of Samples with 3-month Median DO Saturation Below 80%
NZ032	Montezuma Slough, 2nd bend from mouth	1999–2007	3.7%	–
MZ1	Montezuma Slough at Roaring	2000–2011	7.75%	16.7%
MZ2	Montezuma Slough at boat ramp	2000–2011	8.8%	21.2%
SU1	Suisun Slough seining beach	2000–2011	48.2%	83.2%
SU2	Suisun Slough – below Boynton Slough	2000–2011	50.0%	80.7%
SU3	Suisun Slough – above Cordelia Slough	2000–2011	16.2%	22.3%
SU4	Suisun Slough – below Cordelia Slough	2000–2011	14.6%	26.1%
S42	Suisun Slough 300' south of Volanti Slough	1978–1985	11.5%	–
GY1	Goodyear Slough – upper	2000–2011	76.9%	93.8%
GY2	Goodyear Slough – middle	2000–2011	72.1%	90.0%
GY3	Goodyear Slough – lower	2000–2011	31.6%	48.1%
BY1	Boynton Slough – upper	2000–2011	75.7%	95.4%
BY3	Boynton Slough – lower	2000–2011	67.4%	86.9%
PT1	Peytonia Slough – upper	2000–2011	68.1%	92.4%
PT2	Peytonia Slough – middle	2000–2011	66.7%	91.1%
CO1	Cutoff Slough –site 1	2000–2011	36.76%	64.62%
CO2	Cutoff Slough – site 2	2000–2011	33.33%	60.00%
DV2	Denverton Slough – middle	2000–2011	49.26%	67.94%
DV3	Denverton Slough – lower	2000–2011	43.70%	64.34%
NS2	Nurse Slough – middle	2000–2011	24.44%	41.86%
NS3	Nurse Slough – lower	2000–2011	18.94%	37.30%
SB1	Spring Branch – upper	2000–2011	52.94%	83.85%
SB2	Spring Branch – middle	2000–2011	51.85%	81.40%

Data from BDAT Project (P. Moyle personal communication)



(Site SU1, SU2, SU3, and SU4; Source: BDAT Project Moyle, personal communication)

Figure B-3 Percent DO saturation measured at Suisun Slough

A similar pattern of lower DO concentrations was observed in Boynton Slough (Figure B-5), with DO concentrations generally below 7 mg/L, and the median percent oxygen saturation below 80% saturation over a 3-month period for majority of the time (about 90%, Table B-2). DO concentrations and saturation measured at Peytonia Slough showed similar patterns, being frequently below DO objectives for majority of the time (about 70% and 90% of the time respectively, Figure B-6). The lowest DO concentrations generally occurred during the fall months.

DO concentrations at the monitored tributary sloughs are generally below 7 mg/L for over half of the time (Goodyear, Peytonia, and Boynton Sloughs; Table B-2), suggesting potential impairment. DO concentrations measured at Montezuma and Suisun Sloughs also showed concentrations lower than 7 mg/L but the frequency of low DO was significantly reduced and ranged from 7.8 to 8.8% of time and 11.5 to 50.0% of time, respectively.

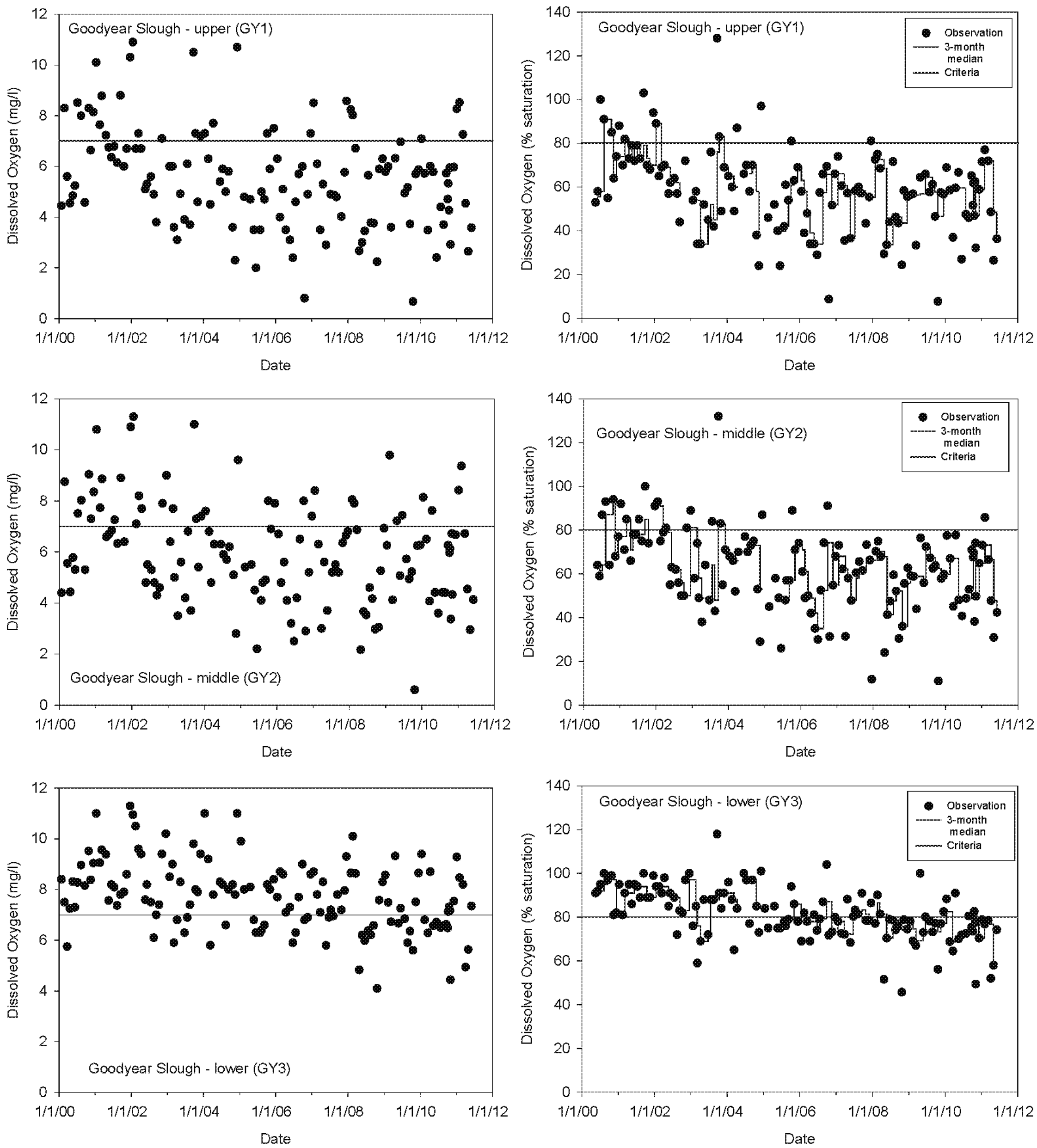
When compared to the 3-month median 80% DO saturation Montezuma Slough data showed that only 16–21% of the samples were below 80% saturation (Table B-2). Suisun Slough data showed that about 80% of the 3-month median DO values were below 80% saturation in the upper slough and 22% of time below water quality objectives in the lower slough. Goodyear, Peytonia, and Boynton Sloughs were routinely below the water quality objective of 80% saturation (86.9 – 93.8% of the time) except for one station at lower Goodyear Slough (GY3).

DO concentrations from Spring Branch, Cutoff, Nurse, and Denverton Sloughs were also compared to the existing DO objectives (Figure B-7 to Figure B-10). The conditions in Cutoff Slough are slightly better than in Spring Branch Slough, possibly due to better mixing with Suisun Slough. Conditions in these two sloughs are the best, possibly due to wider channels that allow better mixing with Montezuma Slough.

DO concentrations were also measured seasonally at several stations in the sloughs in the vicinity of the FSSD WWTP discharge. The locations of these stations are listed in Table B-3. DO concentrations in the receiving water sloughs are shown in Figure B-10. Higher DO concentrations were observed in Chadbourne and Sheldrake Slough than Boynton and Peytonia Slough. The lowest DO concentrations were found at Station CR1 in Peytonia Slough.

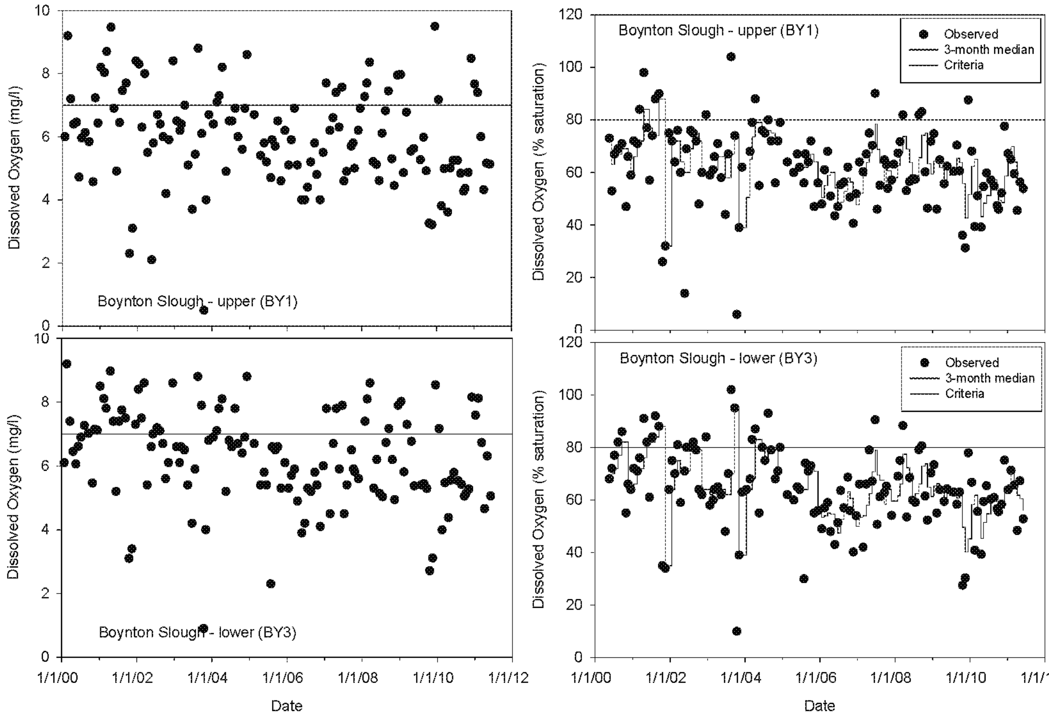
Table B-3
Monitoring stations in receiving water of FSSD discharge in Suisun Marsh

Station	Description
C-1(RW1)	Boynton Slough, about 100 feet downstream from the discharge outfall
C-2 (RW2)	Boynton Slough, about 100 feet downstream from Southern Pacific Railroad crossing
C-3 (RW3)	Boynton Slough, 1800 feet downstream from discharge outfall
C-4 (RW4)	Boynton Slough, in the mouth where it enters Suisun Slough
C-5 (RW5)	Mouth of Sheldrake Slough as it enters Suisun Slough
C-6 (RW6)	Peytonia Slough, in the mouth where it enters Suisun Slough
CR1 (RW7)	Peytonia Slough, about 100 feet downstream from railroad crossing
CR2 (RW8)	Chadbourne Slough, about 100 feet downstream from railroad crossing



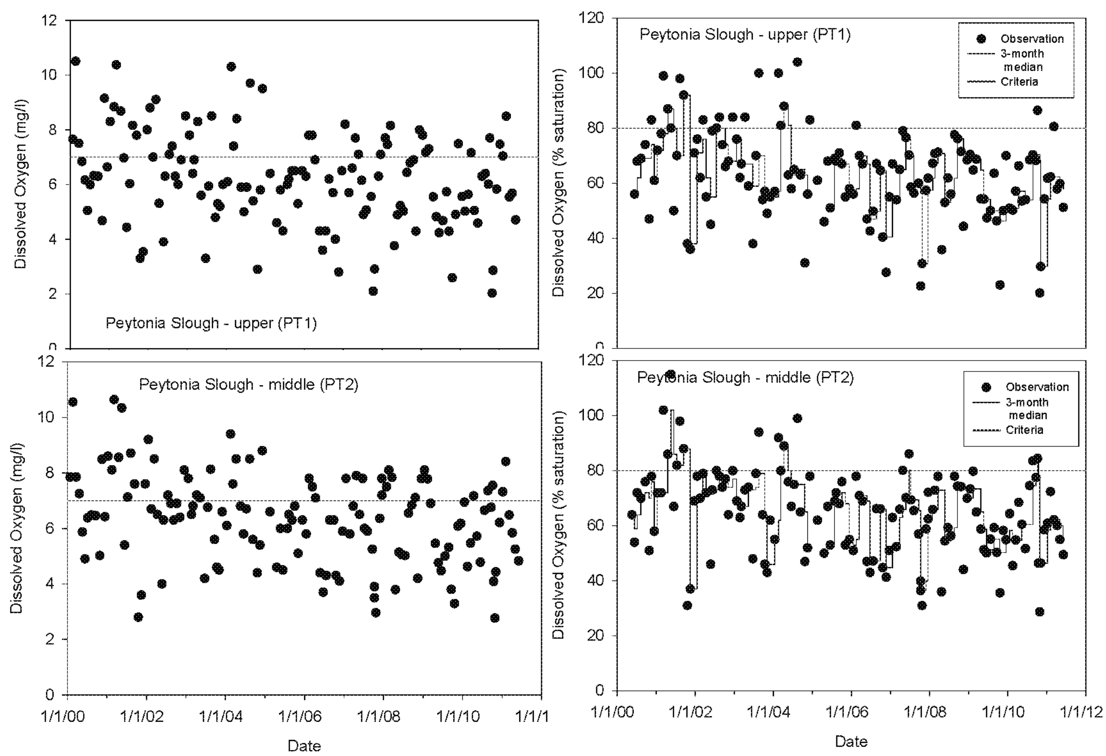
(Site GY1, GY2, and GY3; Source: BDAT Project; Moyle, personal communication)

Figure B-4 DO concentrations and percent oxygen saturation measured at Goodyear Slough



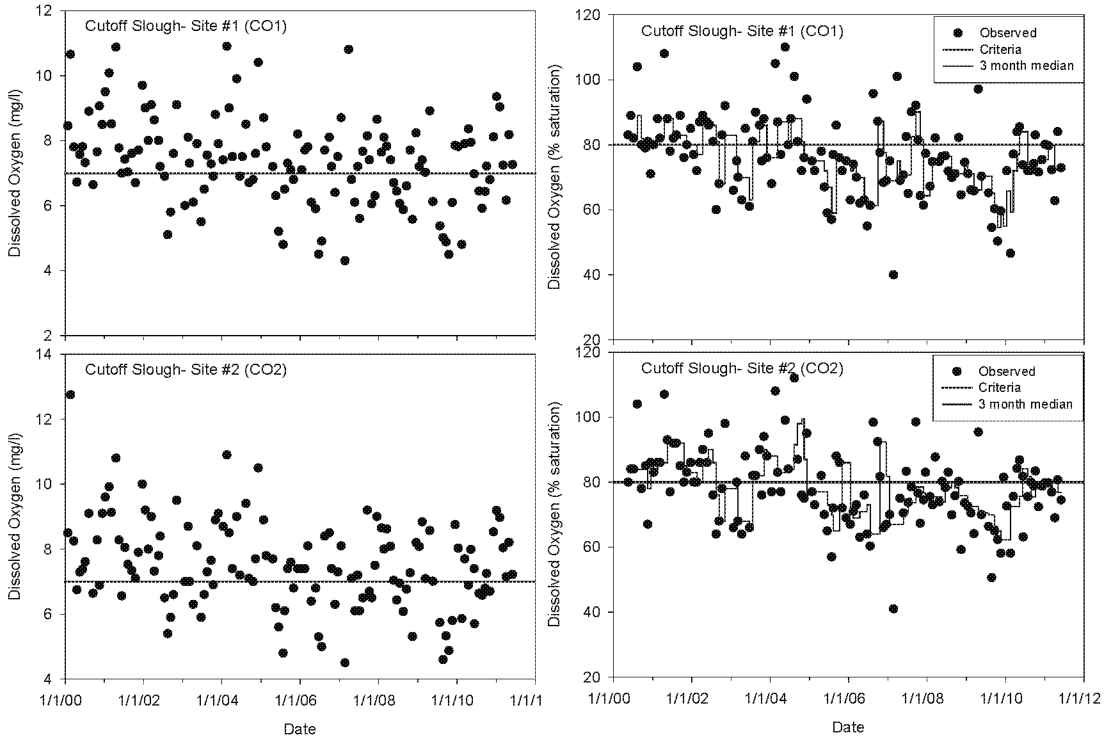
(Site BY1 and BY3; Source: BDAT Project; Moyle, personal communication)

Figure B-5 DO concentrations and percent oxygen saturation measured at Boynton Slough



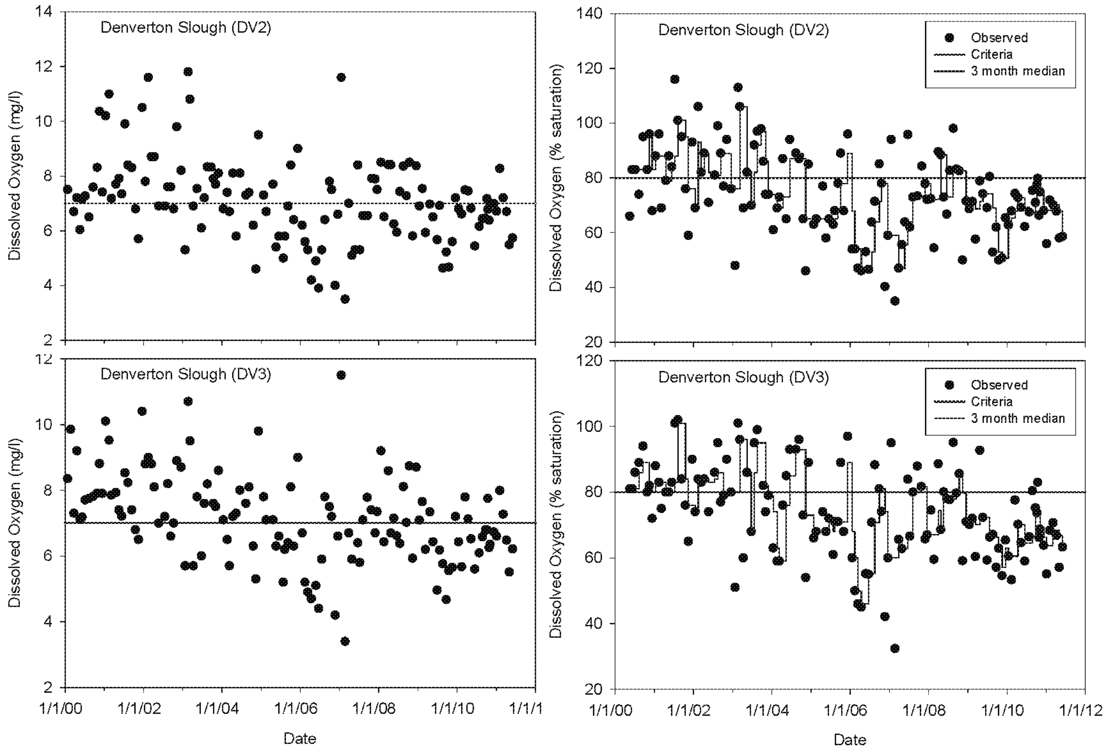
(Site PT1 and PT2; Source: BDAT Project; Moyle, personal communication)

Figure B-6 DO concentrations and percent oxygen saturation measured at Peytonia Slough



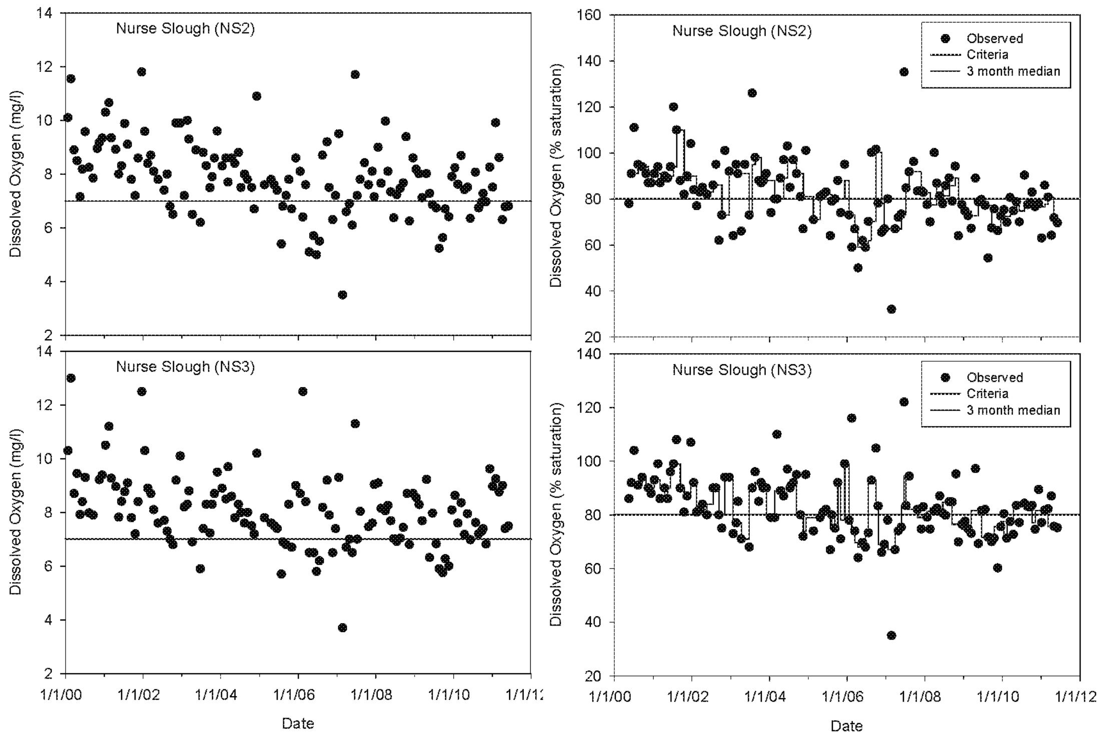
(Site CO1 and CO2; Source: Moyle, personal communication)

Figure B-7 DO concentrations and percent oxygen saturation measured at Cutoff Slough



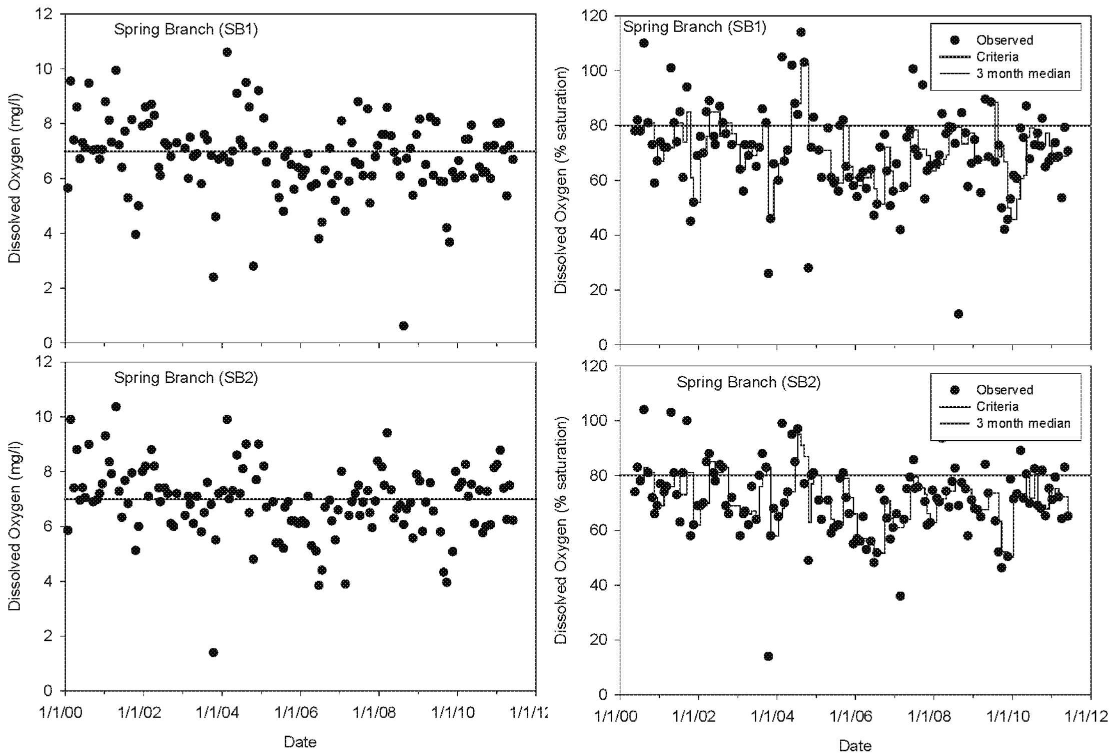
(Site DV2 and DV3; Source: Moyle, personal communication)

Figure B-8 DO concentrations and percent oxygen saturation measured at Denverton Slough



(Site NS2 and NS3; Source: Moyle, personal communication)

Figure B-9 DO concentrations and percent oxygen saturation measured at Nurse Slough



(Site SB1 and SB2; Source: Moyle, personal communication)

Figure B-10 DO concentrations and percent oxygen saturation measured at Spring Branch

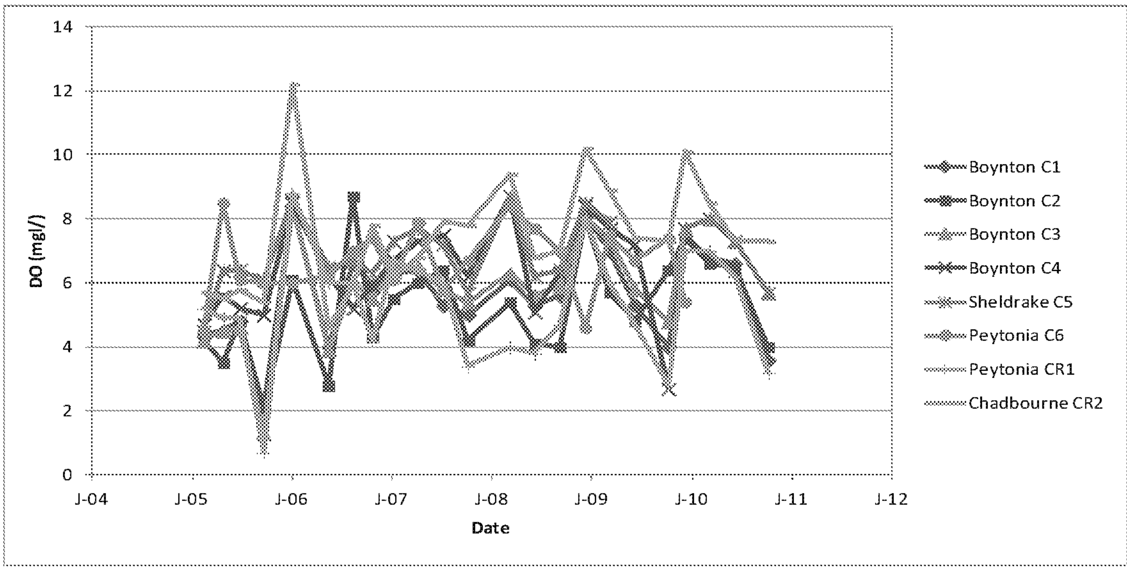


Figure B-11 Receiving water sampling of DO in Suisun Marsh

Comparison of DO Concentrations among the Sloughs

DO concentrations in several sloughs that receive FSSD discharge have been monitored seasonally. These concentrations were compared to concentrations at minimally impacted sites in First and Second Mallard Sloughs, and are similar for the overlapping period (Figure B-12). The concentrations at First and Second Mallard Sloughs were usually slightly lower than those observed at Chadbourne Slough and higher than the concentrations in Boynton and Peytonia Slough. Continuous monitoring data from Goodyear and Denverton Slough, collected by the Regional Water Board, was also used in this comparison. Concentrations in the receiving waters from Boynton and Peytonia Sloughs are similar to Goodyear Slough. Concentrations in Denverton Slough were slightly higher than in Goodyear Slough. Chadbourne Slough, First Mallard, and Second Mallard Sloughs had the highest DO concentrations among all monitored sloughs.

Long-term DO monitoring data for Boynton, Peytonia and Goodyear Sloughs, and continuous monitoring from Goodyear and Denverton Slough, were compared to continuous monitoring data at First and Second Mallard Sloughs (Figure B-13). The results show that long-term DO concentrations in Boynton Slough are generally similar to those in Goodyear Slough, but both were lower than the DO levels in First and Second Mallard Slough. Concentrations from Goodyear Slough are lower than Denverton Slough, particularly during the periods of low DO.

The comparison for Peytonia Slough indicates similar results (Figure B-14). The long-term data in Peytonia Slough showed the upper range of DO concentrations to be similar to First Mallard and Second Mallard Sloughs. The comparison at Goodyear Slough suggested lower concentrations than in First and Second Mallard Sloughs (Figure B-15).

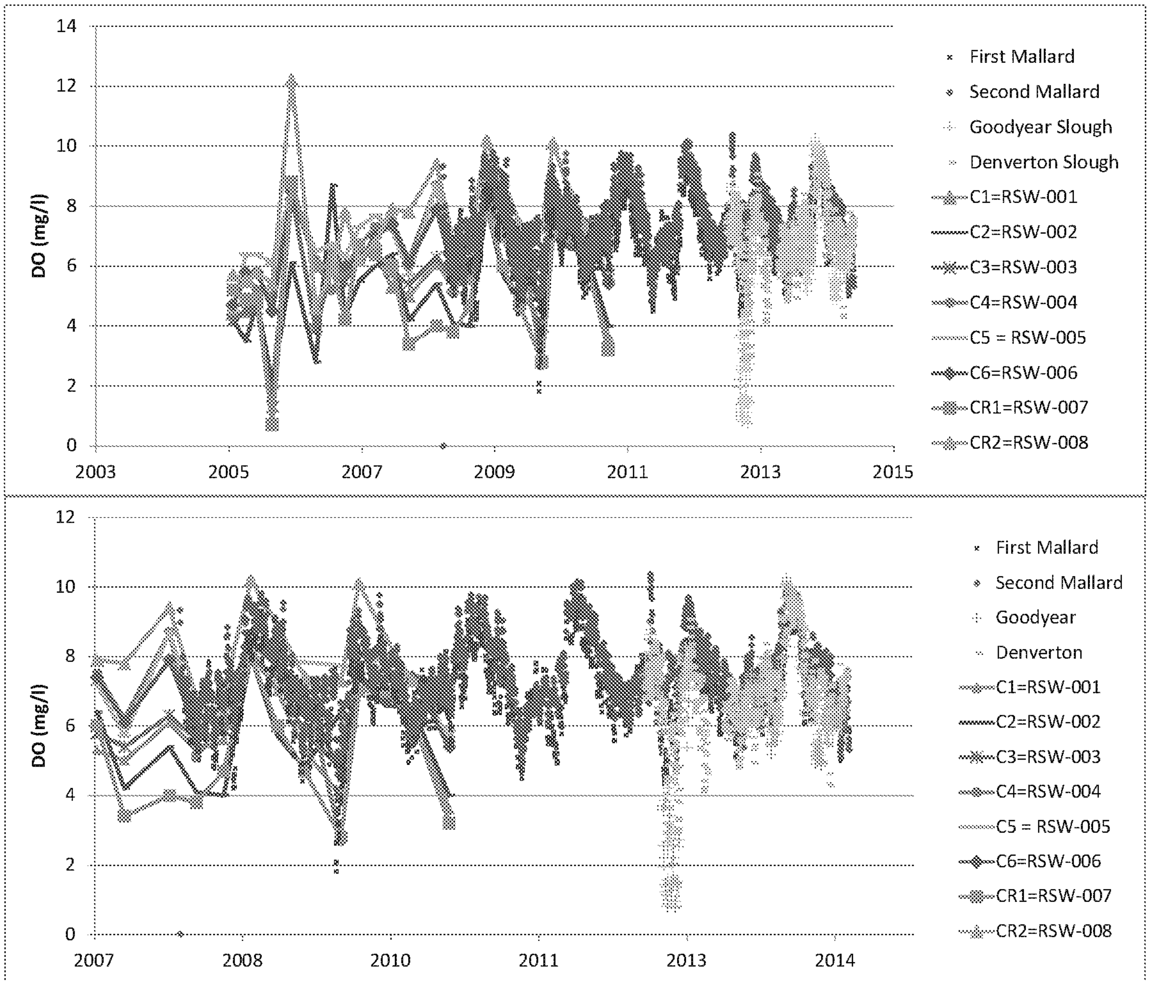


Figure B-12 DO concentrations in receiving water sloughs (seasonally), compared to First Mallard, Second Mallard, Goodyear, and Denverton Sloughs

Notes: Data from NOAA and the Regional Water Board;
15-min readings converted to daily;
C1: Boynton Slough 100 ft downstream from discharge; C2: Boynton Slough 100 ft downstream from Railroad; C3: Boynton Slough 1800 ft downstream from discharge; C4: Boynton Slough mouth; C5: Sheldrake Slough mouth; C6: Peytonia Slough mouth; CR1: Peytonia Slough 100 ft downstream from railroad; CR2: Chadbourne Slough 100 ft downstream from railroad.)

DO concentrations from Spring Branch, Cutoff, Nurse, and Denverton Sloughs were also compared to First Mallard and Second Mallard Sloughs (Figure B-12 to Figure B-18). The results show higher concentrations at First Mallard and Second Mallard Sloughs than the other sloughs. DO concentrations from Spring Branch, Cutoff, and Denverton Sloughs generally bound the lower end of the First Mallard and Second Mallard Slough concentrations. DO concentrations in Nurse Slough were most comparable to the minimally impacted sites.

A summary of the DO concentration data used in this comparison is listed in Appendix A.

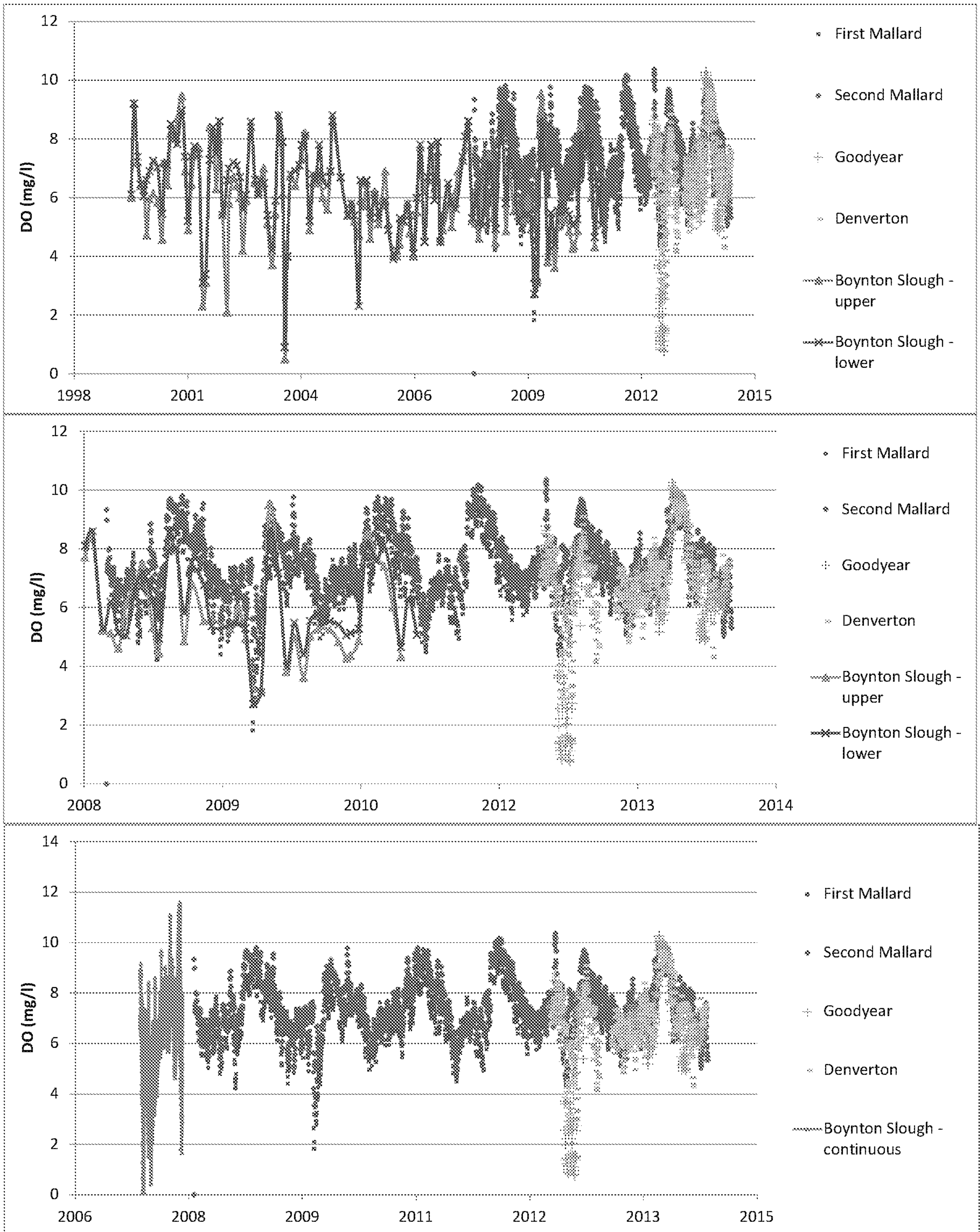


Figure B-13 DO concentrations in Boynton Slough (monthly, measured by UCD and continuous, measured by Sigel et al 2011) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

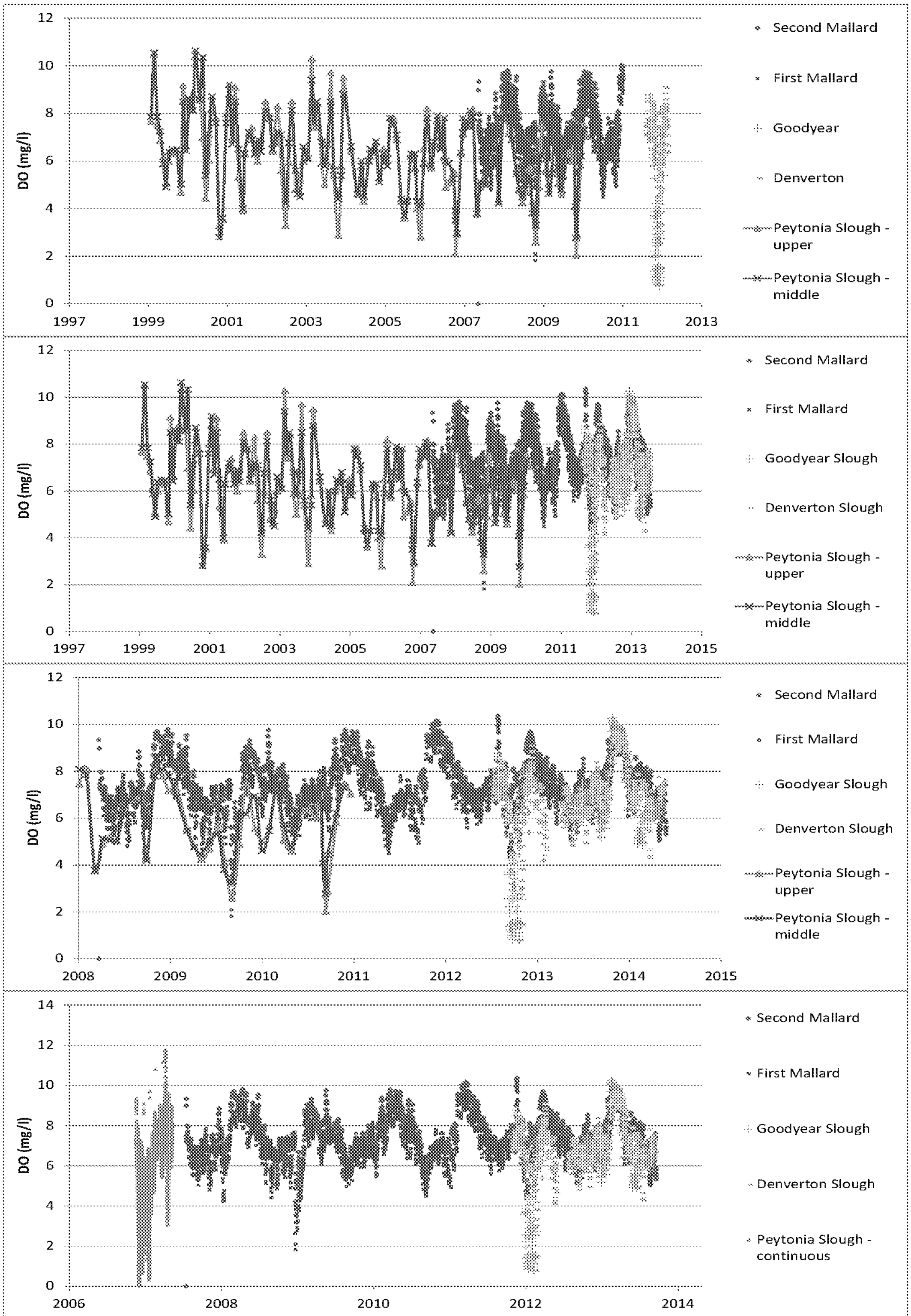


Figure B-14 DO concentrations in Peytonia Slough (monthly, measured by UCD and continuous, measured by Siegel et al 2011) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

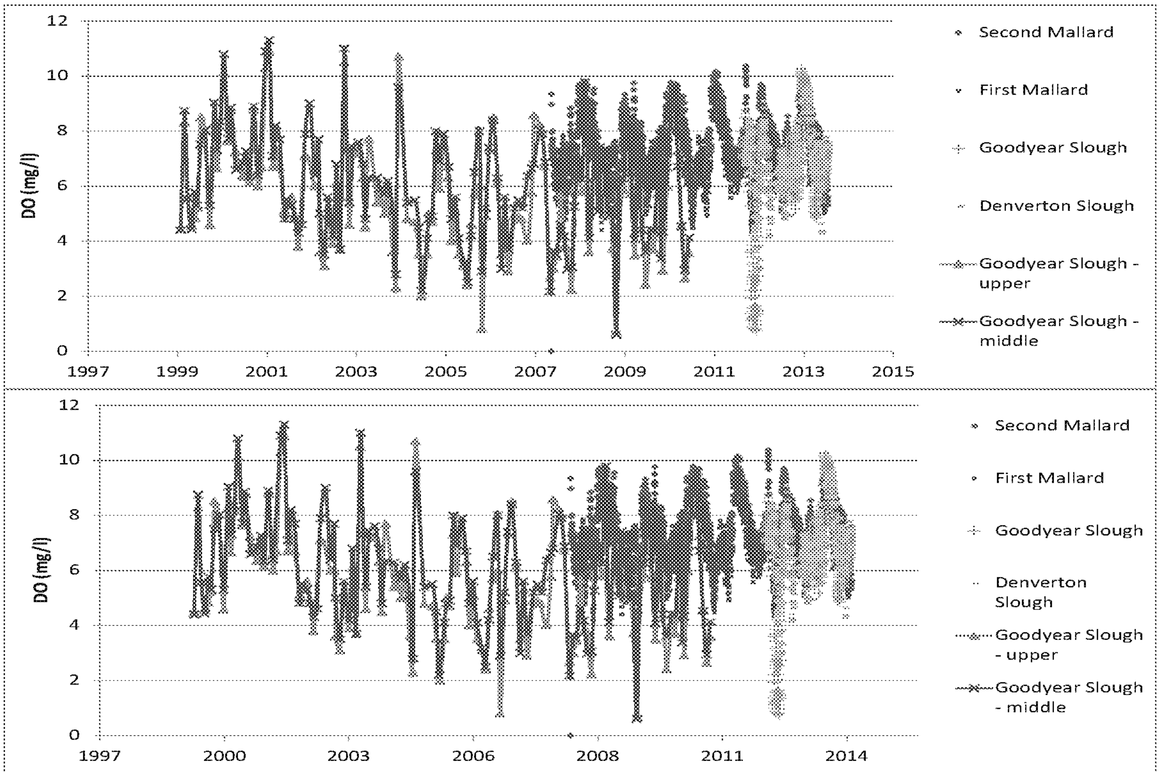


Figure B-15 DO concentrations in Goodyear Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, and Denverton Slough

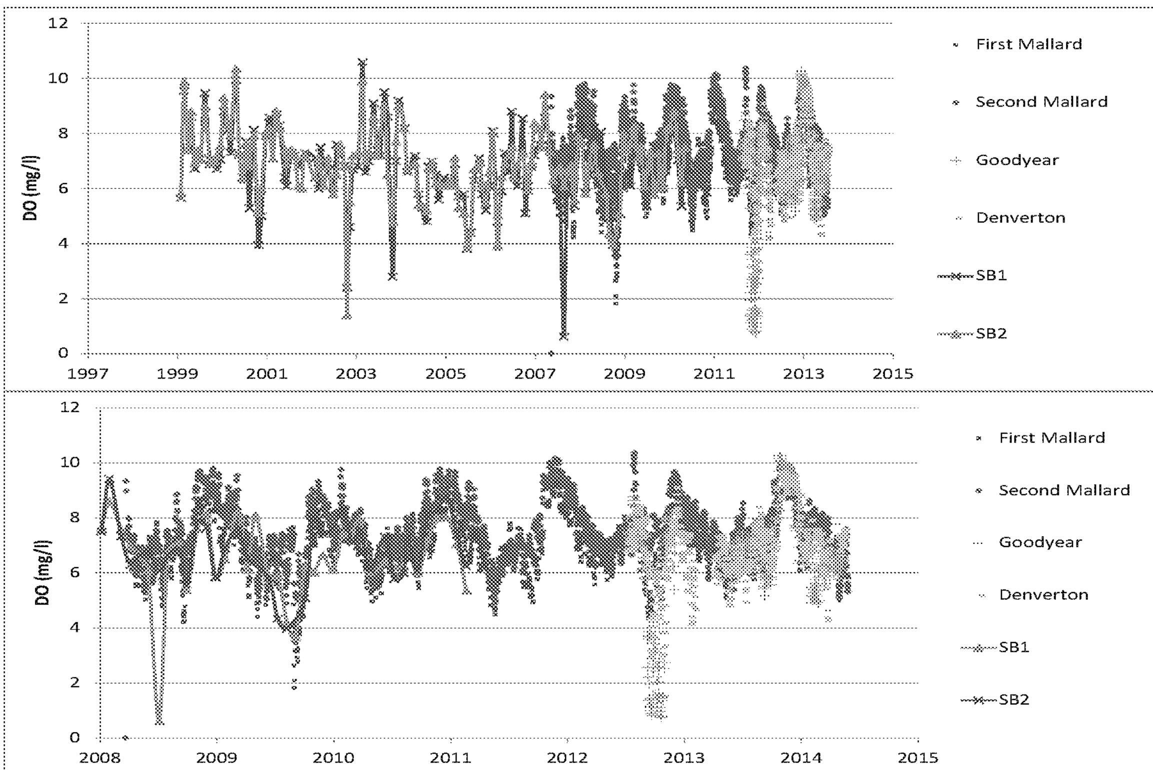


Figure B-16 DO concentrations in Spring Branch (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

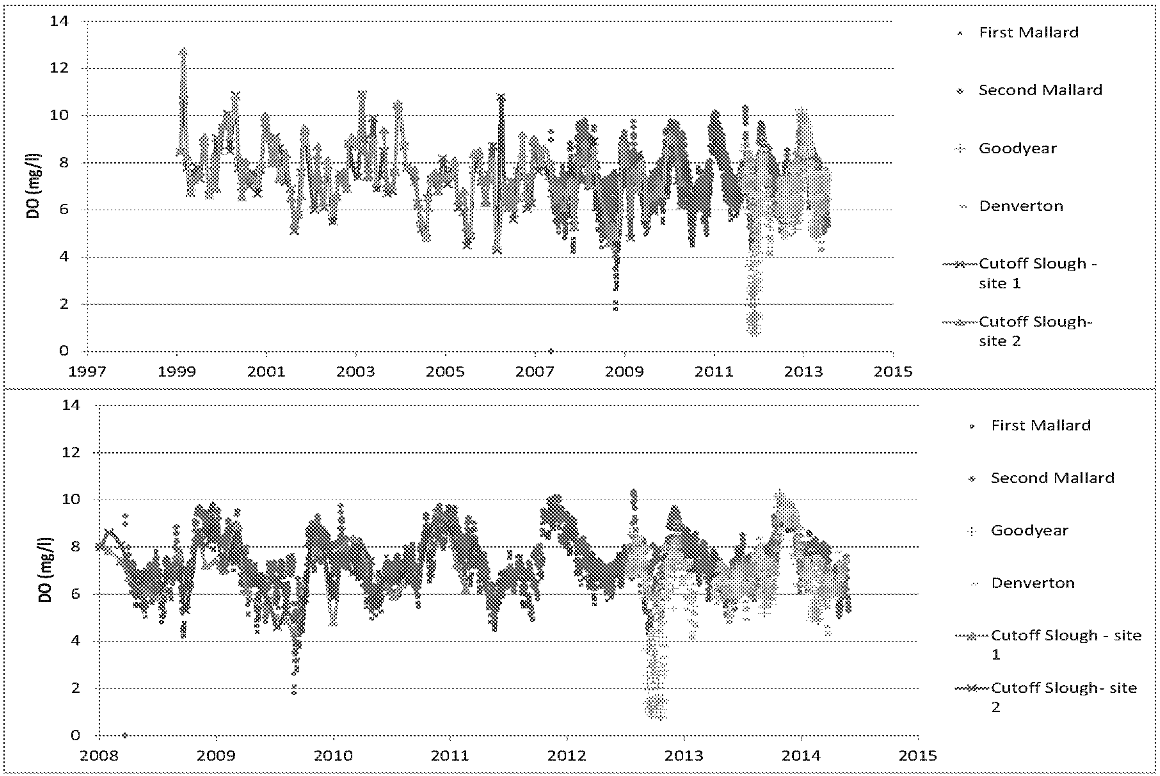


Figure B-17 DO concentrations in Cutoff Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

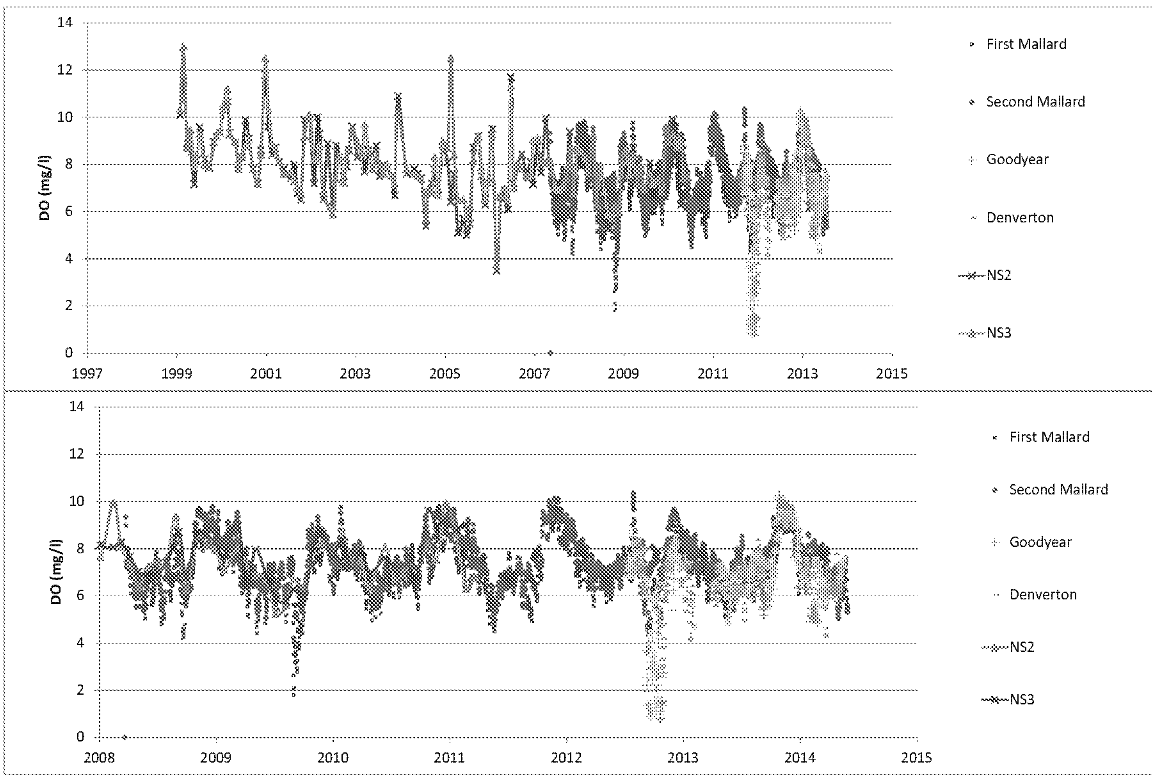


Figure B-18 DO concentrations in Nurse Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

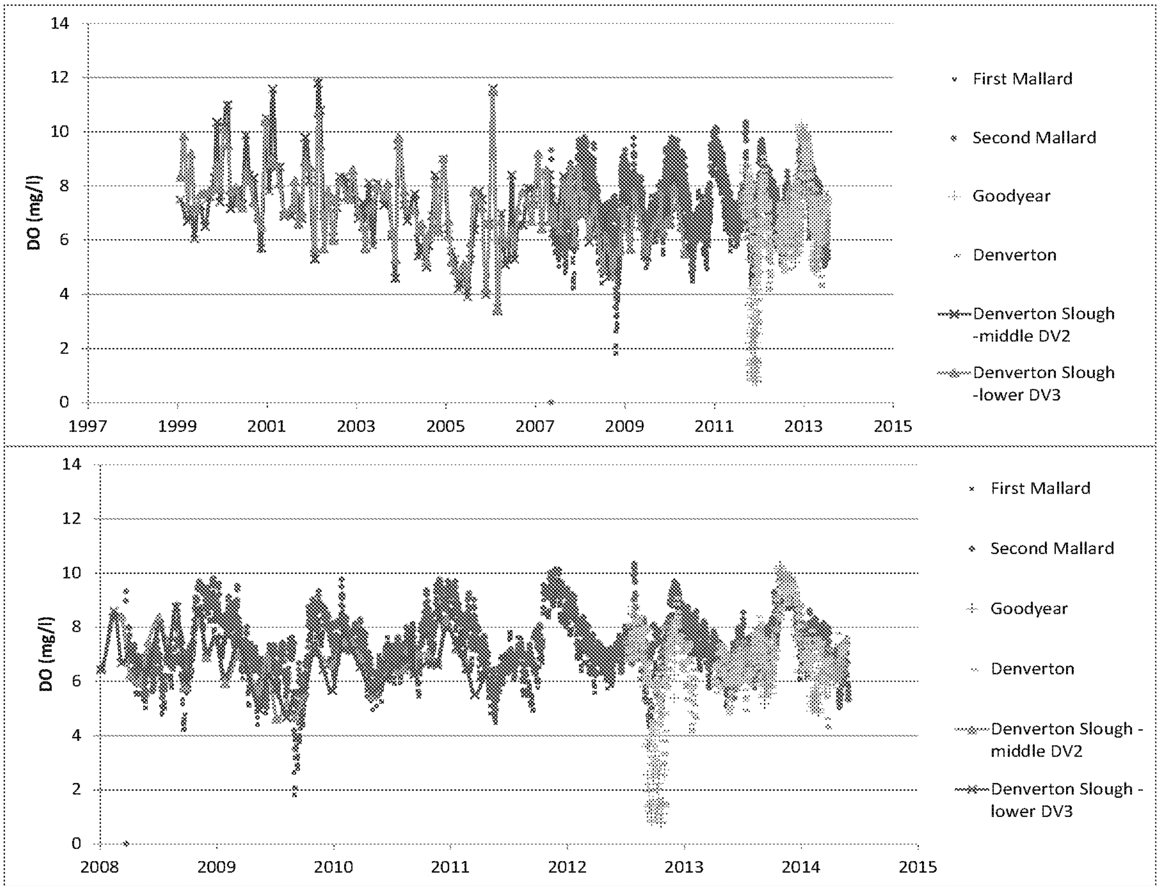


Figure B-19 DO concentrations in Denverton Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

Nutrient Concentrations in Suisun Marsh

Nutrient data are available in Suisun Marsh from sampling conducted more than two decades ago by DWR and from a more recent program conducted over the last decade by FSSD. Because the sampling programs are different, the stations have changed over time.

Nutrient concentrations and total phosphorus (TP) concentrations were measured at Suisun Slough (300' south of Volanti Slough) from 1978–1985 (station S42). Concentrations were as follows:

- Observed ammonia (NH_3) concentrations for this period ranged from 0 to 0.30 mg/L.
- Organic nitrogen concentrations ranged from 0.1 to 1.5 mg/L.
- Observed total Kjeldahl nitrogen (TKN) ranged from 0.5 to 1.8 mg/L.
- Observed nitrite + nitrate ($NO_2 + NO_3$) concentrations ranged from 0 to 0.9 mg/L.

The organic nitrogen and $NO_2 + NO_3$ concentrations are relatively high, and could result in high phytoplankton levels. For example, a total inorganic nitrogen concentration of 0.15 mg/L could result in maximum chlorophyll a of 150 µg/L in the region (Tetra Tech, 2006) and a TN concentration of 1.5 mg/L (approximated in this case as the sum of TKN and nitrite plus nitrate) was considered as a boundary of mesotrophic-eutrophic conditions (Dodds et al. 1998). Ortho-P (PO_4) concentrations in Suisun Slough ranged from 0.02 to 0.19 mg/L. TP concentrations range from 0.1 to 0.35 mg/L. Observed TN/TP ratios are usually below 16 (the Redfield ratio, representing stoichiometric ratios of nitrogen:phosphorus in biomass). This suggests that nitrogen is more likely to be limiting algal growth. Nitrogen has been found to be the predominant limiting nutrient in coastal marine systems. However, both N and P limitation is widespread and the importance of N and P limitation needs local assessment (Elser et al. 2007).

More recently, during 2000–2011, nutrient concentrations were measured in the receiving waters of the FSSD discharge in several tributary sloughs within Suisun Marsh. These include a total of 8 stations, located in Boynton Slough (4 stations), Peytonia Slough (2 stations), Sheldrake Slough (1 station) and Chadbourne Slough (1 station); DO concentrations from Spring Branch, Cutoff, Nurse, and Denverton Sloughs were also compared with the existing DO objectives (Figure B-7 to Figure B-10). The conditions in Cutoff Slough are slightly better than in Spring Branch Slough, possibly due to better mixing with Suisun Slough. Conditions in these two sloughs are the best, possibly due to wider channels that allow better mixing with Montezuma Slough.

DO concentrations were also measured seasonally at several stations in the sloughs adjacent to the FSSD wastewater discharge. The locations of these stations are listed in Table B-3. DO concentrations in the receiving water sloughs are shown in Figure B-11. Higher DO concentrations were observed in Chadbourne and Sheldrake Slough than Boynton and Peytonia Slough. The lowest DO concentrations were found at Station CR1 in Peytonia Slough.

The observed ammonia concentrations in Boynton Slough were generally in the range of 0–0.4 mg/L (Figure B-21). The concentrations were slightly higher than previously observed in Suisun Slough (0–0.3 mg/L). Ammonia concentrations in Peytonia, Sheldrake, and Chadbourne Sloughs were generally similar to concentrations in Boynton Slough, with a range of 0–0.4 mg/L, with values over 0.4 mg/L occurring in a few instances.

Organic nitrogen concentrations were generally in the range of 0.5–2.0 mg/L in Boynton and Peytonia Sloughs (Figure B-21). Concentrations in Sheldrake and Chadbourne Slough were slightly lower ranging from 0.3 to 1.5 mg/L. The organic nitrogen concentrations in these sloughs are higher than previously observed in Suisun Slough (0.2–1.0 mg/L).

TKN concentrations ranged from 1–2 mg/L in Boynton Slough and Peytonia Slough and showed an increasing trend in recent years (i.e., from 2000–2011; Figure B-22). TKN concentrations in Sheldrake and Chadbourne Sloughs were slightly lower, at 0.3–1.5 mg/L. The range of TKN concentrations in Sheldrake and Chadbourne Sloughs was similar to that previously observed in Suisun Slough (0.5–1.4 mg/L).

Relatively high NO_3 concentrations were observed in Boynton Slough (0–18 mg/L), particularly for stations above and below the FSSD and managed wetland discharges

(Figure B-23). Stations near the mouth of the slough showed the lowest concentrations. Nitrate concentrations in other sloughs are somewhat lower (generally below 2 mg/L). Overall, however, nitrate concentrations observed in these tributary sloughs are much higher than previously observed in Suisun Slough (0–0.8 mg/L).

Higher than in other sloughs concentrations of ortho-P (0.5–4 mg/L) were observed in Boynton Slough (Figure B- 24). Concentrations in Peytonia Slough were generally below 1 mg/L. Sheldrake and Chadbourne Sloughs showed lower concentrations, ranging from 0 to 0.6 mg/L. Concentrations observed in these sloughs are higher than previously observed in Suisun Slough (0.1 – 0.35 mg/L).

The concentrations for ammonia across the stations were generally similar (Figure B-25). Organic nitrogen and TKN concentrations were higher at headwaters of Boynton Slough and lower at Chadbourne Slough. Nitrate concentrations showed a very clear pattern of higher concentrations at stations in Boynton Slough, with lower concentrations in Peytonia and other sloughs. The observed ortho-P concentrations showed a similar pattern, with higher concentrations at stations in Boynton Slough than Peytonia and other sloughs (Figure B-26).

The observed NO_3 concentrations measured as part of the receiving water study by the FSSD were compared to concentrations at minimally impacted sites at First Mallard and Second Mallard Sloughs (Figure B-27). The results suggested elevated NO_3 concentrations in the receiving water sloughs, particularly in Boynton Slough and, to a lesser degree, in Peytonia Slough as compared to the minimally impacted sites. The NO_3 concentrations were highest in Boynton Slough, followed by Peytonia Slough, and were lowest in Chadbourne Slough. Higher concentrations in the receiving water sloughs could be due to discharges from FSSD and managed wetlands.

The observed NH_4 concentrations in the receiving water sloughs of Suisun Marsh were compared to concentrations at minimally impacted sites. The results suggested higher NH_4 concentrations in the receiving waters than in First Mallard and Second Mallard Sloughs (Figure B-28). The higher NH_4 concentrations in the receiving waters could be due to discharges from FSSD and managed wetlands.

The comparison of PO_4 concentrations in the receiving water sloughs to First and Second Mallard Sloughs similarly suggested higher concentrations in the receiving water sloughs than the minimally impacted sites (Figure B-29). The highest PO_4 concentrations were observed in Boynton Slough, followed by Peytonia Slough. The PO_4 concentrations in Sheldrake and Chadbourne Sloughs were similar to the minimally impacted sites.

Taken together, the results presented here suggest that higher nutrient concentrations in the receiving waters could be attributed to discharges from FSSD and the managed wetlands.

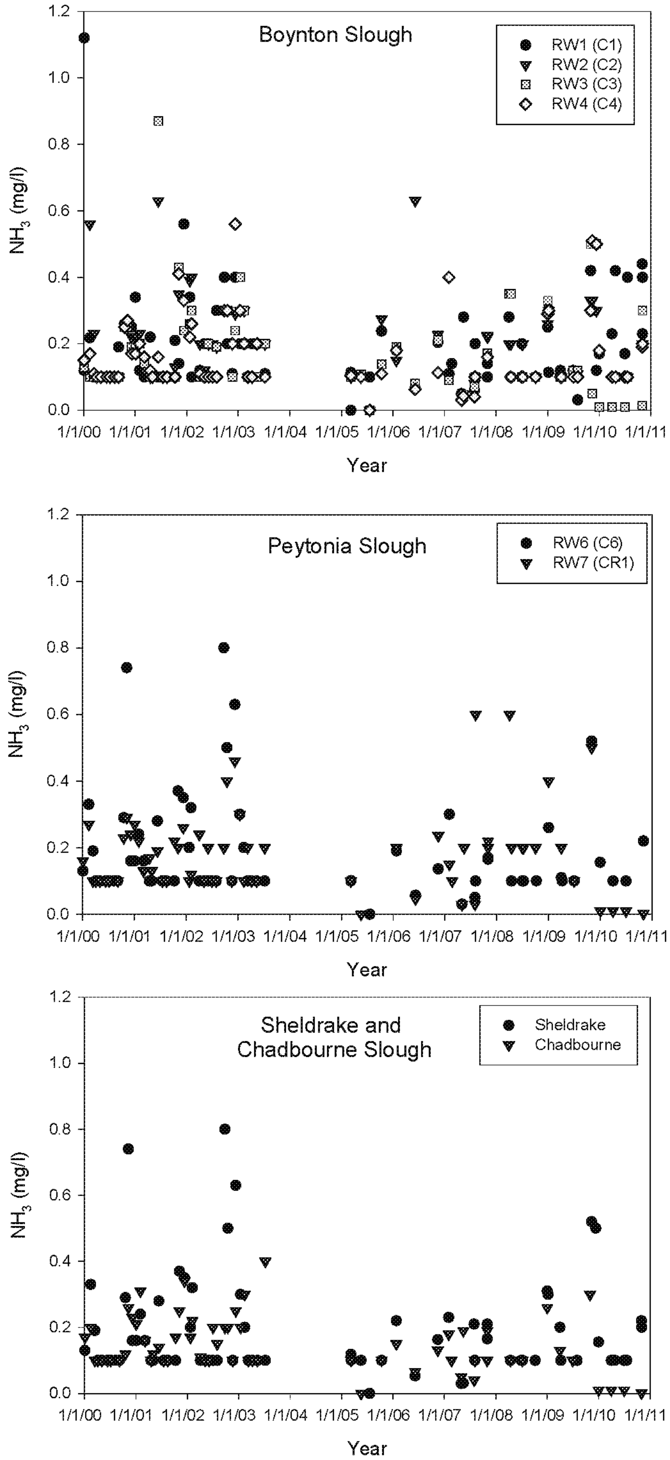


Figure B-20 Observed NH_3 concentrations in the waters of Suisun Marsh in the vicinity of FSSD

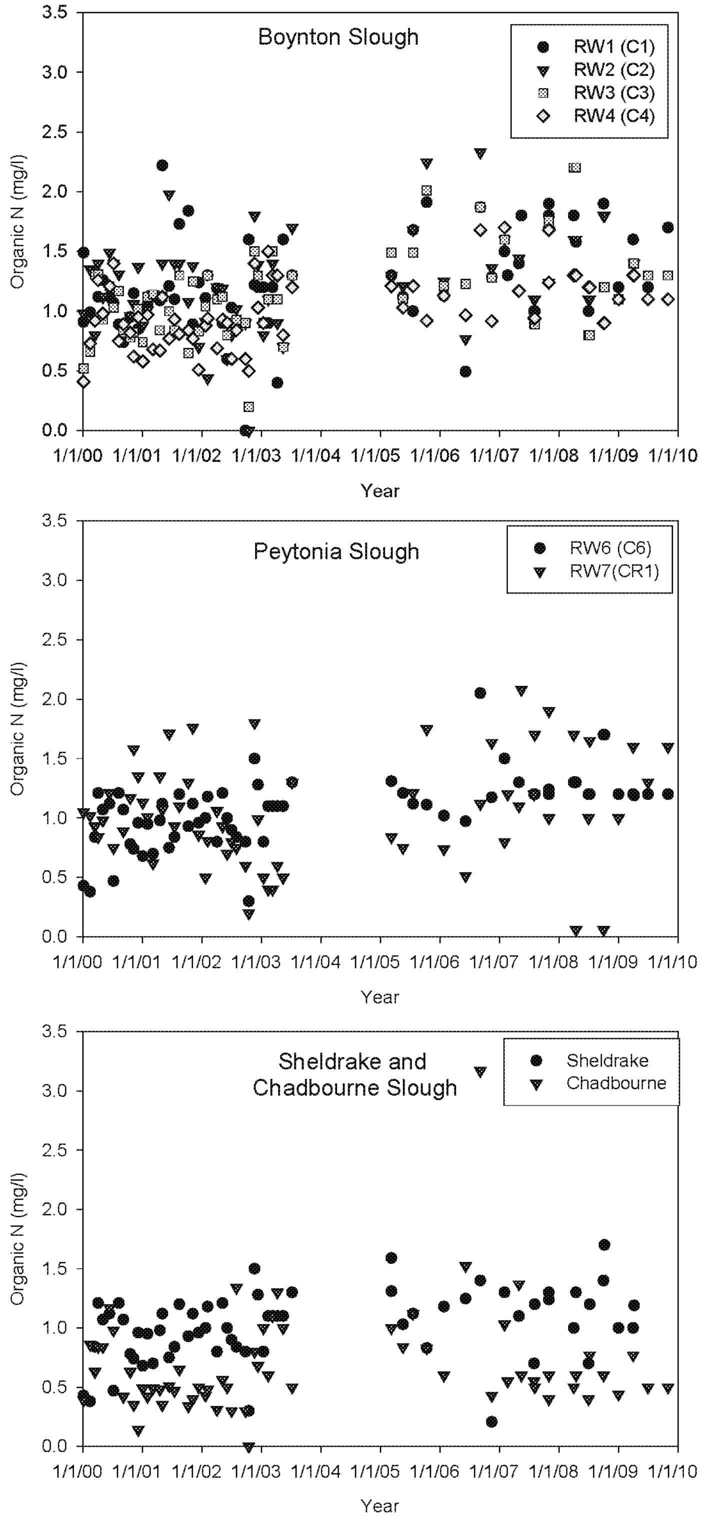


Figure B-21 Observed organic nitrogen concentrations in the waters of Suisun Marsh in the vicinity of FSSD

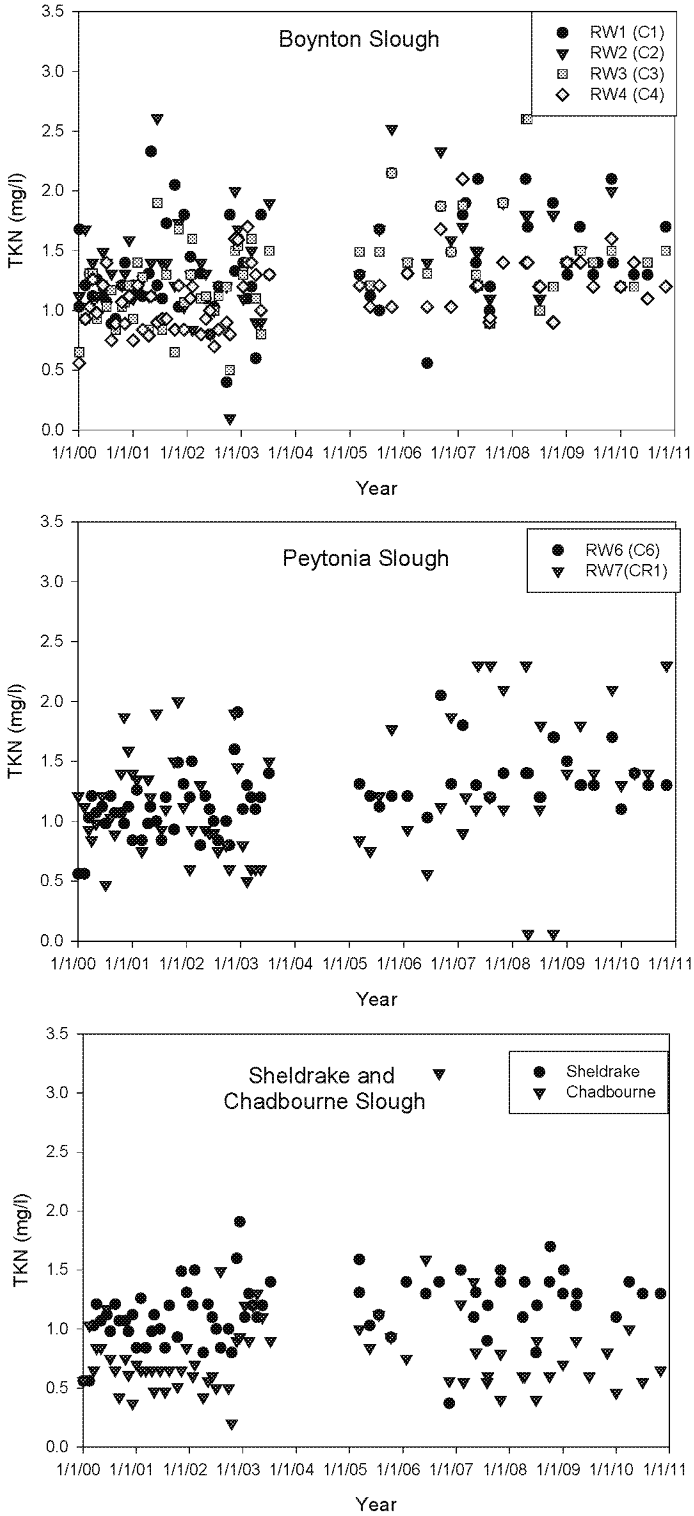


Figure B-22 Observed TKN concentrations in the waters of Suisun Marsh in the vicinity of FSSD

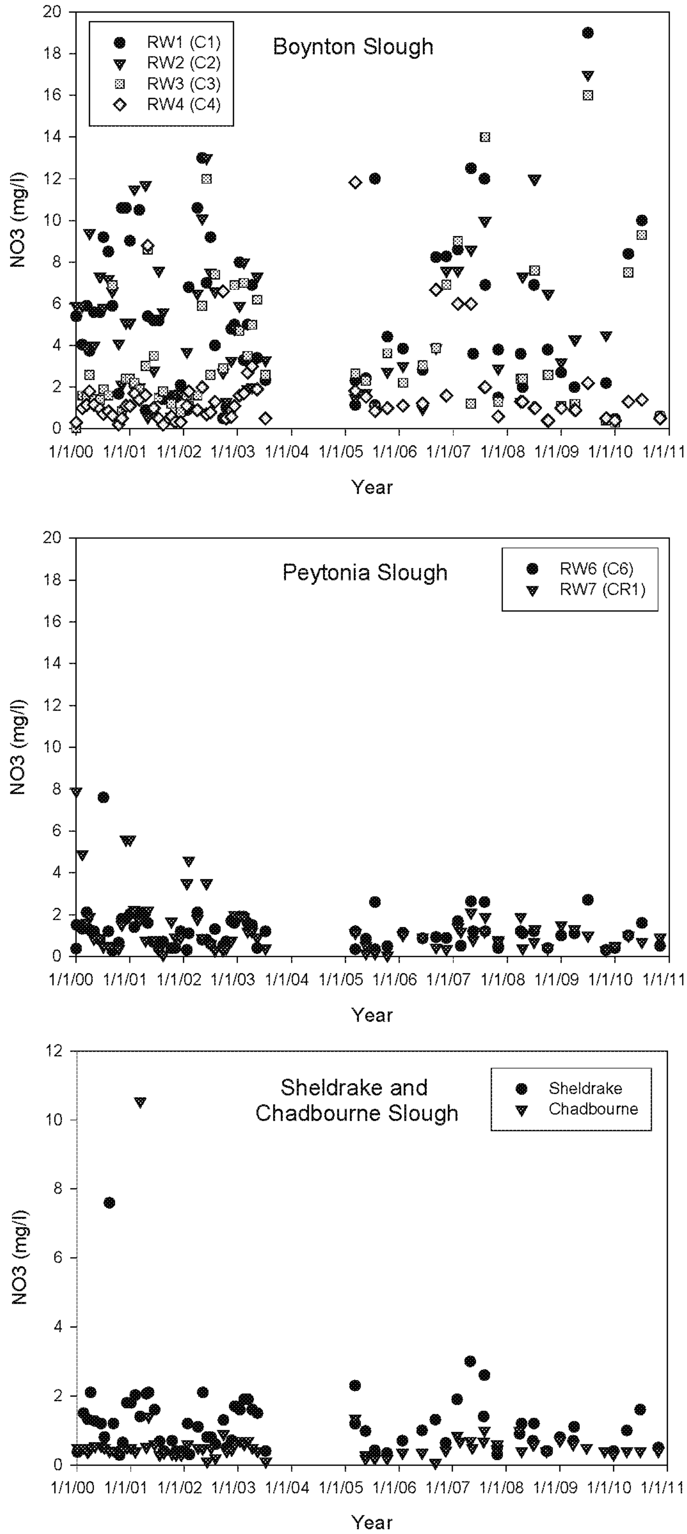


Figure B-23 Observed NO_3 concentrations in the waters of Suisun Marsh in the vicinity of FSSD

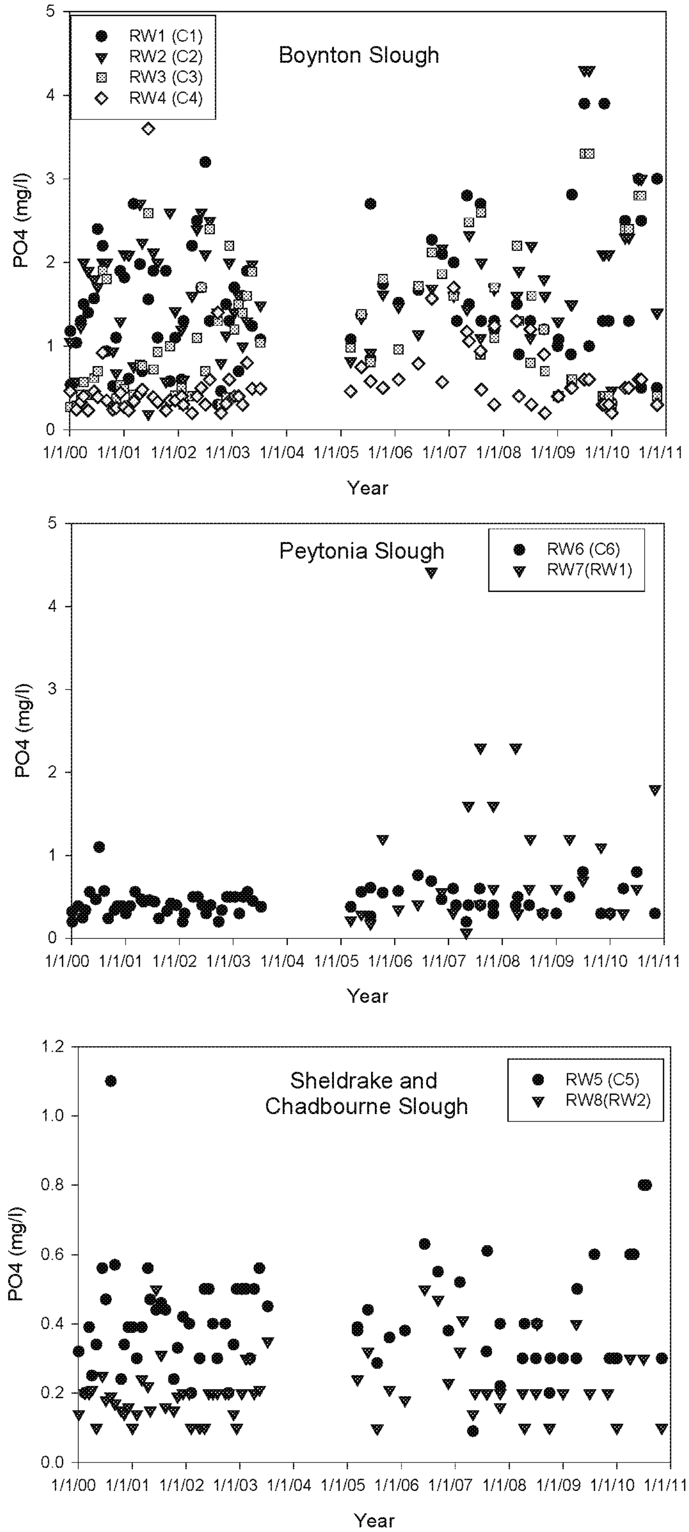


Figure B- 24 Observed ortho-P (PO_4) concentrations in the waters of Suisun Marsh in the vicinity of FSSD

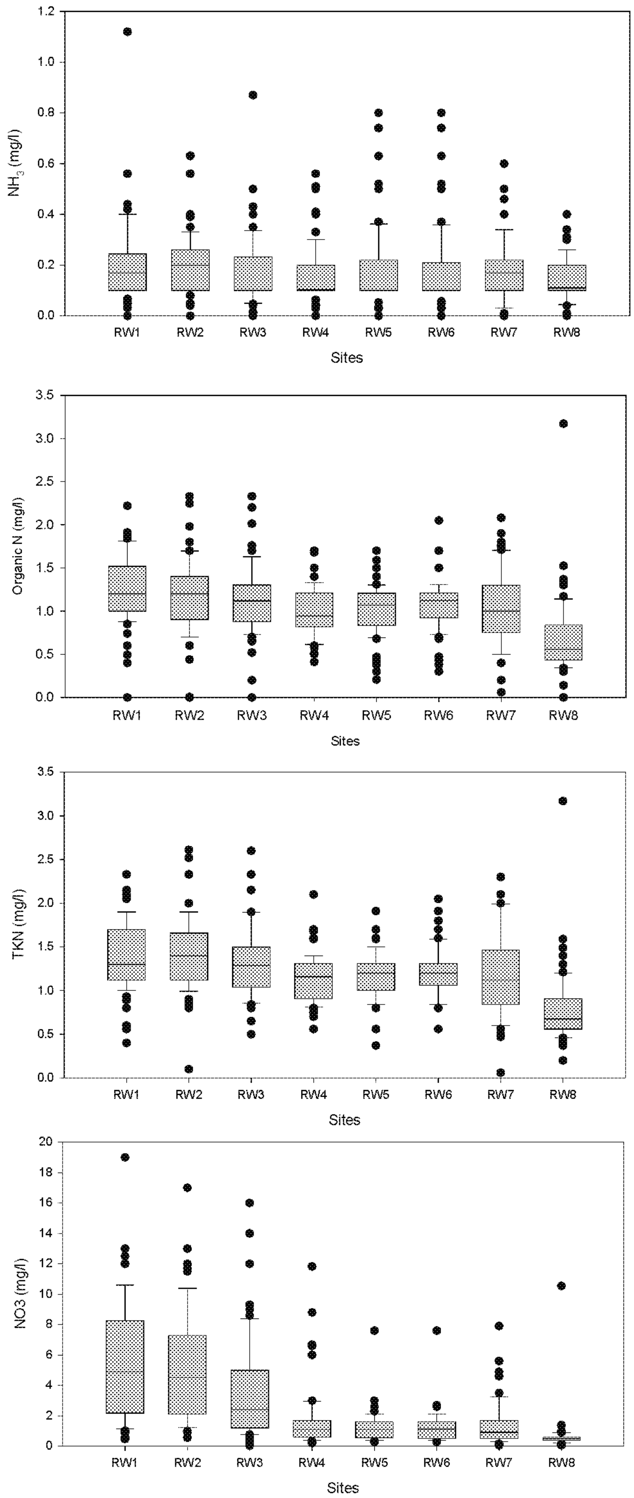


Figure B-25 Box plots of observed nitrogen concentrations in the waters of Suisun Marsh in the vicinity of FSSD

The upper and lower ends of the box represent the 75th and 25th percentiles of the data, the line represents the median, and the whiskers represent the 10th and 90th percentiles.

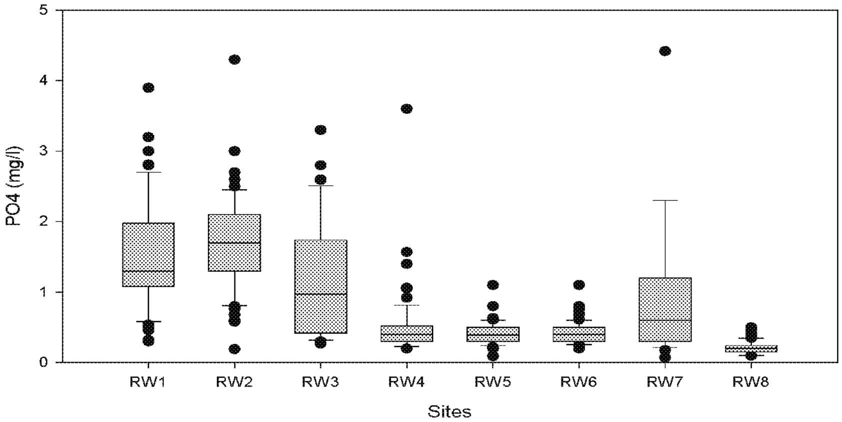


Figure B-26 Box plot of observed ortho-P (PO_4) concentrations in the receiving waters of Suisun Marsh

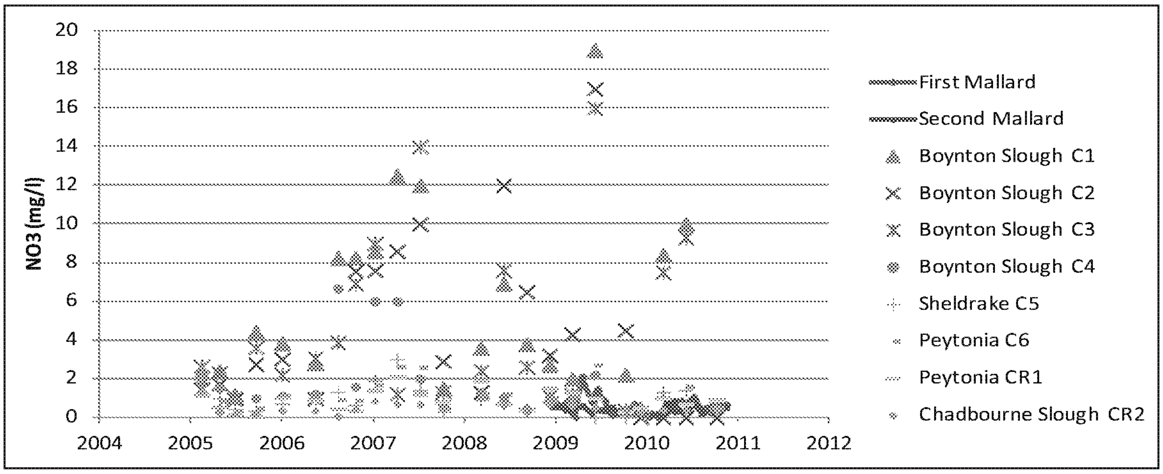


Figure B-27 Observed nitrate (NO_3) concentrations in the receiving waters compared to concentrations at First and Second Mallard Sloughs

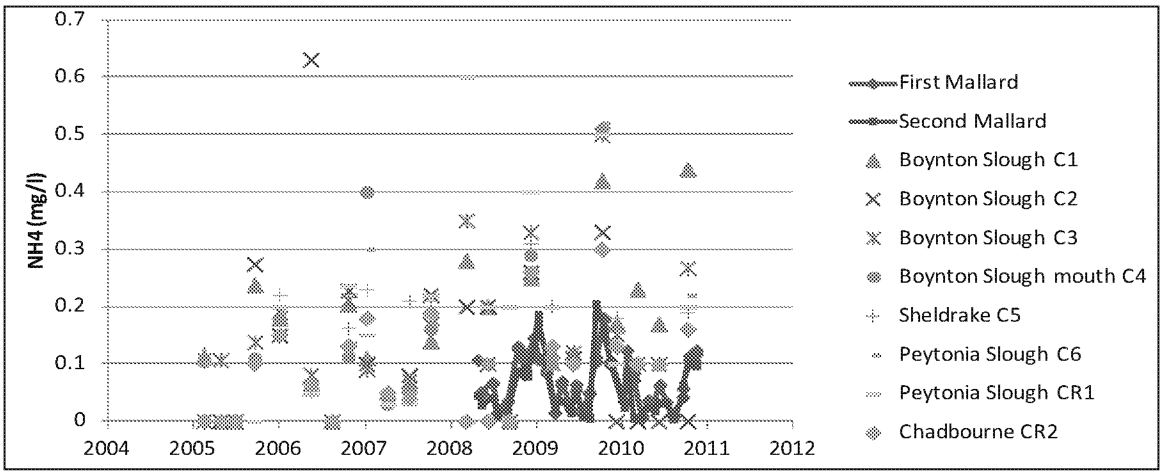


Figure B-28 Observed ammonia (NH_4) concentrations in the receiving waters compared to concentrations at First and Second Mallard Sloughs

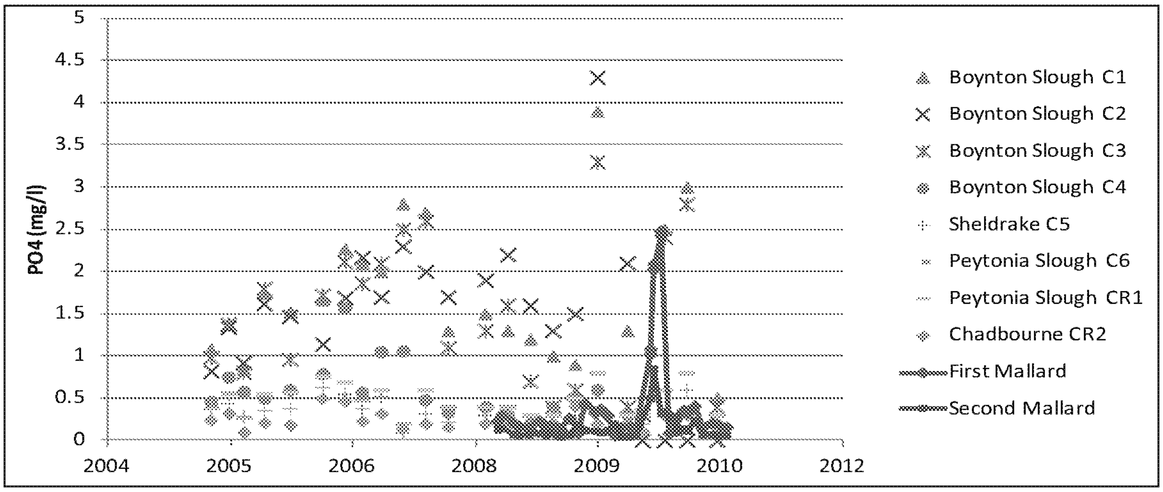


Figure B-29 Observed phosphate (PO_4) concentrations in the receiving waters compared to concentrations at First and Second Mallard Sloughs

Chlorophyll a Concentrations in Suisun Marsh

High nutrient concentrations potentially result in excess growth of phytoplankton, which, in turn, supports production of organic carbon and could result in low DO concentrations, increases in turbidity, or decreases in water clarity and Secchi depth.

Chlorophyll a concentrations were measured in Boynton and Peytonia Sloughs and two other sloughs (Sheldrake and Chadbourne Sloughs). Chlorophyll a concentrations in these sloughs are similar to concentrations measured at the minimally impacted sites: First and Second Mallard Sloughs near Cutoff Slough (Figure B-30). Chlorophyll a concentrations showed a seasonal pattern with higher concentrations in the summer and lower concentrations in the winter, and generally ranged between 2–40 µg/L. The concentrations in the sloughs are considered to be relatively high. Although nutrient concentrations were higher in the receiving water sloughs than the minimally impacted sites (First and Second Mallard Sloughs), the observed chlorophyll a concentrations in these sloughs are similar to the minimally impacted sites. This suggests that naturally occurring nutrient concentrations can contribute to relatively high chlorophyll a concentrations.

Limited chlorophyll a data are available in Montezuma Slough (station NZ032). Since 1998, observed chlorophyll a concentrations at NZ032 have been relatively constant, ranging between 2–5 µg/L, with some elevated concentrations above 5 µg/L (Figure B-31). The chlorophyll a concentrations were higher in the tributary sloughs than in Montezuma Slough.

Chlorophyll a concentrations have also been measured at the managed wetlands 112 and 123 (Figure B-32; Bachand et al. 2010). These concentrations could be extremely high (100–400 µg/L) during phytoplankton blooms. For Wetland 123, phytoplankton blooms occurred frequently during September to November and again in February to April. In Wetland 112, phytoplankton blooms occurred for longer periods. The observed chlorophyll a concentrations in managed wetlands strongly suggest conditions that favor algae growth, such as nutrient enrichment, long residence times, and lack of the filter-feeding *C. amurensis*.

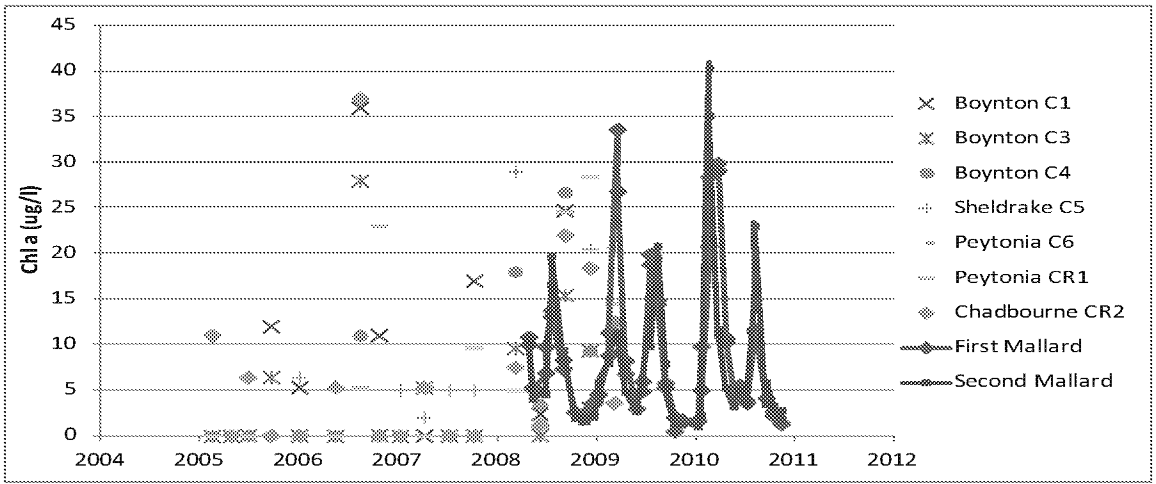


Figure B-30 Observed Chlorophyll a concentrations in receiving water sloughs compared to First and Second Mallard Sloughs

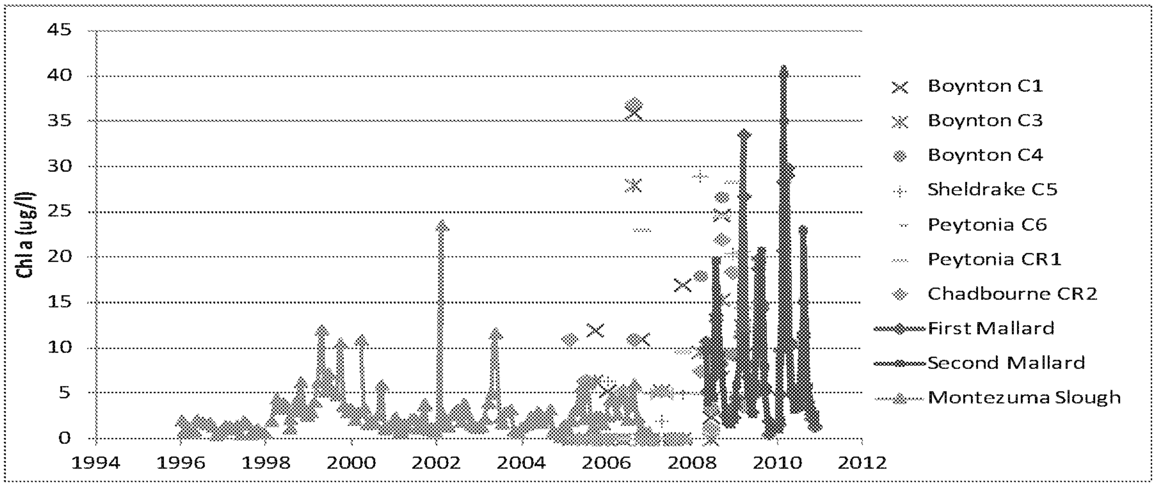


Figure B-31 Observed Chlorophyll a concentrations in receiving water sloughs compared to First and Second Mallard Sloughs and Montezuma Slough

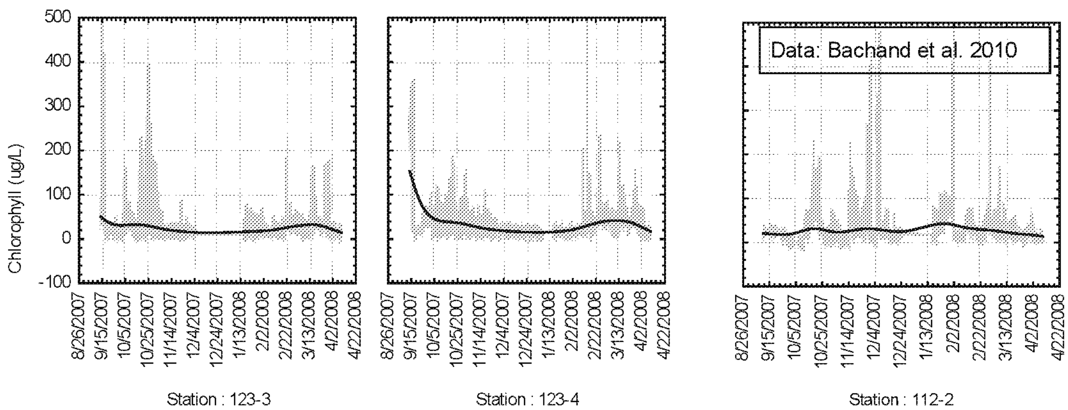


Figure B-32 Temporal chlorophyll a trends a perimeter stations for wetlands 112 and 123.

Conditions at Minimally Impacted Sloughs

Many sloughs within Suisun Marsh receive direct discharges from managed wetlands, and/or are substantially modified and affected by human activities. There are some sloughs, however, which are fully tidal, have good connectivity to larger sloughs (Suisun, Montezuma) or to the Bay, and do not receive discharges from managed wetlands. These sloughs were used here to represent background conditions in the marsh. Two such sloughs with water quality data were identified in Suisun Marsh: First Mallard and Second Mallard Slough. DO concentrations in First Mallard and Second Mallard Sloughs are monitored continuously by NOAA under the National Estuarine Research Reserve System's (NERRS) National Monitoring Program. These two stations are located at the intersection of Cutoff Slough with First Mallard and Second Mallard Sloughs, which drain different regions of the San Francisco Bay National Estuarine Research Reserve. First Mallard Slough drains the northwestern portion of Rush Ranch, while Second Mallard Slough drains the southeastern areas (Figure B-33). The area draining to these sloughs consists mostly of tidal marshes and non-tidal wetlands, covered by natural vegetation.

EPA recommends the use of natural background conditions in establishing the numeric site–specific criteria for temperature, DO, and pH for the protection of aquatic life designated uses (EPA 2015). The frameworks suggests that when appropriate data exist and when the non-attainment of the water quality criterion is due to natural processes, natural background conditions can be used to set site-specific criteria, regardless whether the existing water quality objectives are met or not. When deciding whether a given condition represents natural conditions, factors such as 1) undisturbed vegetation surrounding the site; 2) no historical anthropogenic impacts; 3) presence of evident hydrological alteration; 4) groundwater recharge is not impacted by anthropogenic activities; 5) no point or non-point source discharges. These conditions are met to a significant degree at the First Mallard and Second Mallard Sloughs and therefore these sloughs may be reasonably considered to represent natural background conditions or minimally impacted sites in Suisun Marsh.

Figure B-33 Locations of First and Second Mallard Slough monitoring stations

The daily average DO concentrations at First Mallard Slough range between 2 to 9.5 mg/L. The daily average DO concentrations at Second Mallard Slough range between 3.5 to 10 mg/L. Daily average DO concentrations at these two locations are compared to the existing DO objectives of 7 mg/L and 5 mg/L, and the 3-month medians of daily average DO saturation were compared to the objective of 80% saturation. In addition, hourly minimum DO concentrations were compared to the EPA recommended DO criteria for continuous exposure of saltwater, modified to aquatic life in Suisun Marsh: 1) 3.3 mg/L for criterion minimum concentration (CMC) for juvenile and adult organism survival for persistent exposure; 2) 5.0 mg/L for criterion continuous concentration (CCC) for growth effects on aquatic organisms for persistent exposure, and 3) criteria for episodic exposure based on hours of exposure to adjusted CMC and CCC (EPA, 2000; Table B-4). These thresholds are based on laboratory tests of biological effects of low DO to aquatic life, and therefore protect the survival and growth of estuarine species. The results of the evaluation are shown in Figure B-34 to Figure B- 39 and summarized in Table B-5 and Table B-6.

For the First Mallard Slough, when compared to the existing criterion of 7 mg/L, about half of the data points (51.7%) were below 7 mg/L, but only a few points (4.4% of the time) were below 5 mg/L. However, First Mallard Slough is below 80% DO saturation for most of the time. The comparison to persistent exposure criteria of CMC and CCC showed some incidences of not meeting the persistent exposure criteria. The hourly DO data are below continuous exposure criteria CMC occasionally (for 0.14% of the time), and below CCC 0.65% of the time. The comparison to sub-daily or episodic exposure criteria suggested some incidences of not meeting the adjusted CMC (0.25% of the time) or with cumulative growth reduction greater than 25% (1.36% of the time).

Table B-4
Summary of ambient aquatic life water quality criteria for DO recommended in EPA (2000) modified to aquatic life in Suisun Marsh

Endpoint	Persistent Exposure (24 hrs or greater continuous low DO condition)	Episodic and cyclic exposure (less than 24 hr duration of low DO conditions)
Juvenile and adult survival (minimum allowable conditions)	(1) A limit for continuous exposure **DO = 3.3 mg/L** (criterion minimum concentration, CMC)	(3) a limit based on the hourly duration of exposure **DO = 0.566* ln(t) + 1.4976** Where: DO = allowable concentration (mg/L) T = exposure duration (hours)
Growth effects (maximum conditions required)	(2) A limit for continuous exposure **DO = 5.0 mg/L** (criterion continuous concentration, CCC)	(4) a limit based on the intensity and hourly duration of exposure Cumulative cyclic adjusted percent daily reduction in growth must not exceed 25% $\Sigma \frac{ti * 1.56 * Gredi}{24} < 25\%$ And Gredi = -23.1*DOi + 138.1 Where: Gredi = growth reduction (%) DOi = allowable concentration (mg/L) Ti = exposure interval duration (hours) I = exposure interval

For the Second Mallard Slough, about 40% of the daily DO data are below 7 mg/L, however, with only a few data points below 5 mg/L during the time period monitored (0.38% of the time). Second Mallard Slough is below 80% DO saturation for over 78% of the time. The data showed no incidence of exceeding the persistent exposure criteria. The minimum hourly DO is below continuous exposure criteria CMC of 3.3 mg/L occasionally but for less than 24 hours, and the occasional incidences of DO below CCC of 5.0 mg/L do not last longer than 24 hours. For exposure less than 24 hours, the minimum hourly DO concentrations were occasionally less than the adjusted CMC (14 hours or 0.03% of the time). There are rare incidences of cumulative growth effects of greater than 25% (39 hours total, 0.07% of the time) for exposure less than 24 hours.

First and Second Mallard Sloughs can be considered to represent natural background conditions in Suisun Marsh. The fact that DO concentrations about 50% of the time in First Mallard Slough and 40% of the time in Second Mallard Slough were below the Basin Plan criterion of 7 mg/L suggests that this criterion cannot be met all the time even under no direct discharges from managed wetlands. Both First and Second Mallard Sloughs showed only a few occasions where concentrations were below 5 mg/L, suggesting that under the conditions of no direct discharges from the managed wetlands, the Cutoff Slough region in Suisun Marsh is able to meet a 5 mg/L target most of the time (>95% of the time, Table B-5 and Table B-6). The comparison to biological criteria of CMC and CCC at these two sloughs suggested that these criteria can be met more than 98% of the time.

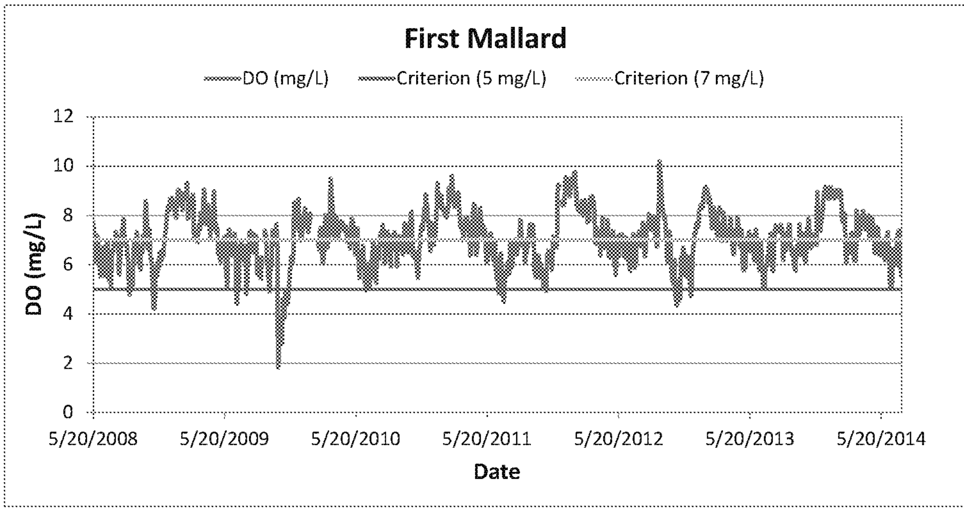


Figure B-34 Daily average DO at First Mallard Slough compared to the DO criteria of 5 and 7mg/L

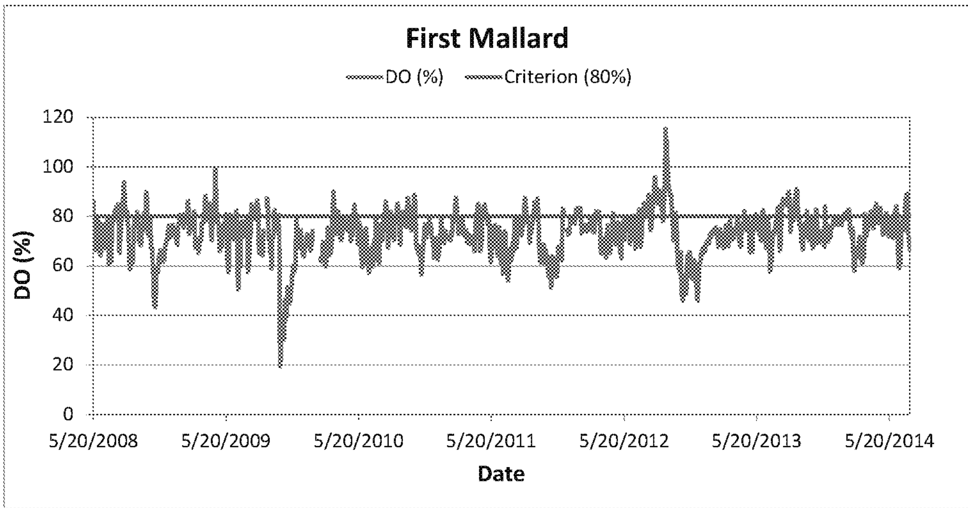
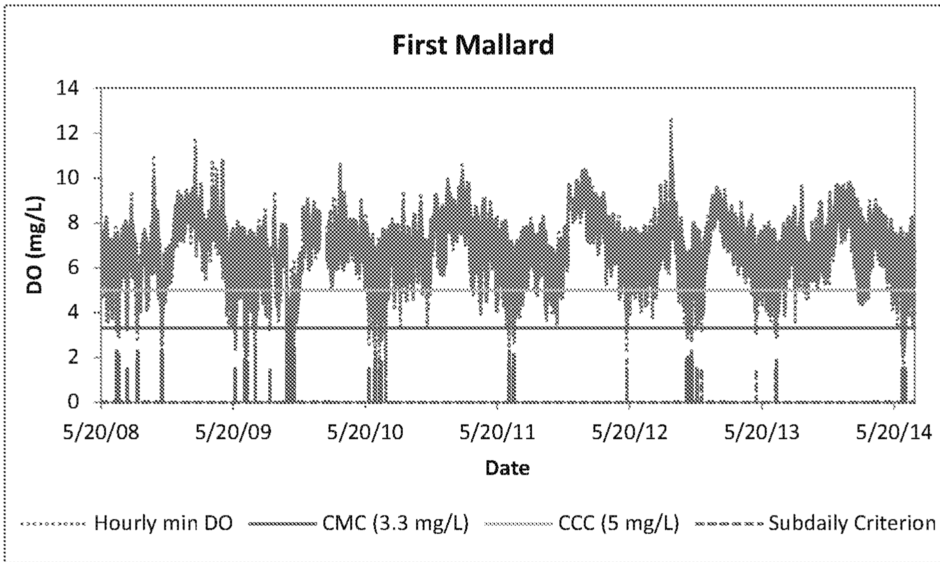


Figure B-35 Daily average DO at First Mallard Slough compared to 80% of DO saturation



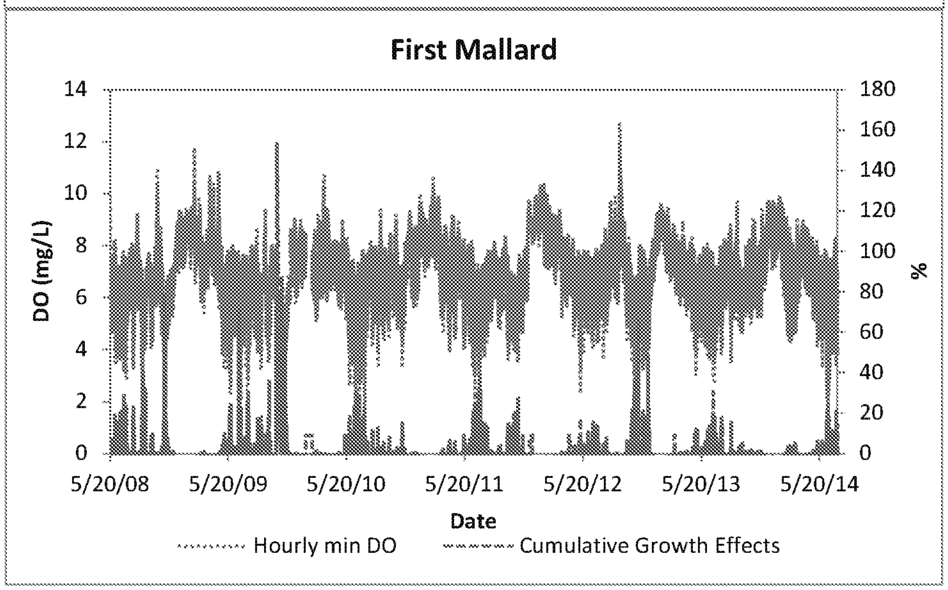


Figure B-36 Hourly DO concentrations compared to the criterion minimum concentration (CMC) and criterion continuous concentration (CCC) at First Mallard Slough

Table B-5
Summary of time below DO criterion for the First Mallard Slough

	Days below criterion of 5 mg/L	Days below criterion of 7 mg/L	Number of rolling 3-Month median of daily DO below 80% saturation	Hours below CMC of 3.3 mg/L	Hours below CCC of 5 mg/L	Hours below adjusted CMC* (based on hourly duration of exposure)	Hours with cumulative growth reduction >25%*
Number	71	1050	2074	76	346	131	716
Total Data Points	2209	2209	2155	52841	52841	52841	52841
Percent	3.21%	47.53%	96.24%	0.14%	0.65%	0.25%	1.36%

*EPA, 2000

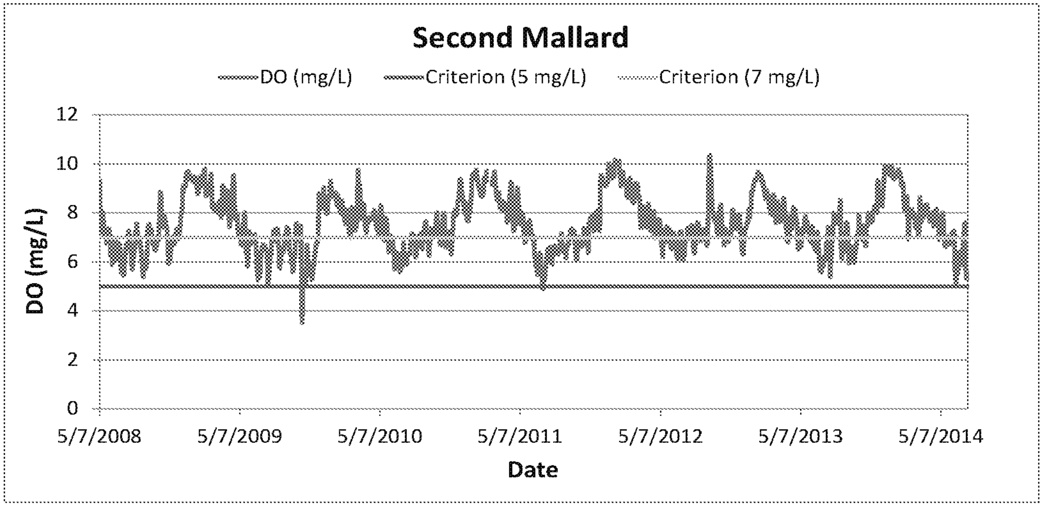


Figure B-37 Daily average DO concentrations at Second Mallard Slough compared to the DO criteria of 5 and 7mg/L

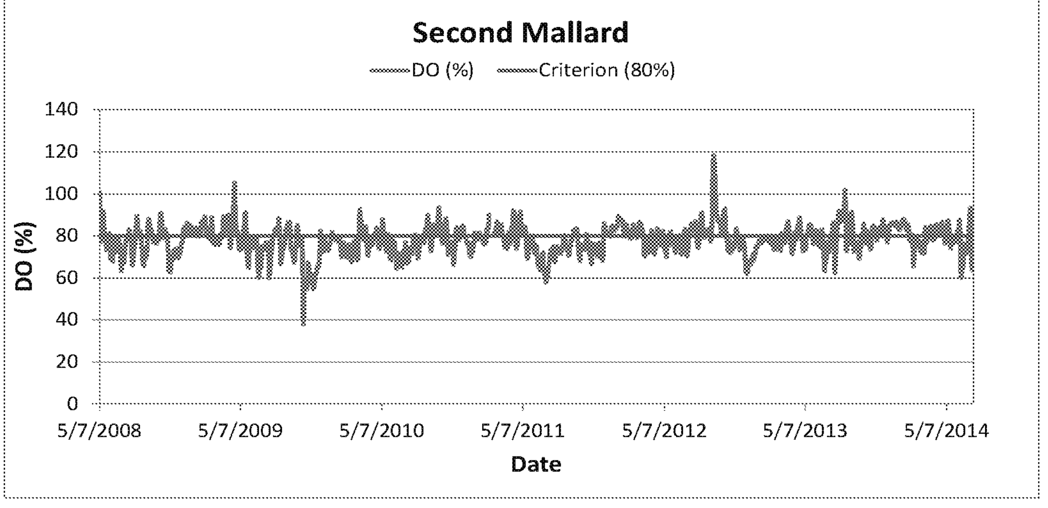


Figure B-38 Daily average DO concentrations at Second Mallard Slough compared to 80% of DO saturation

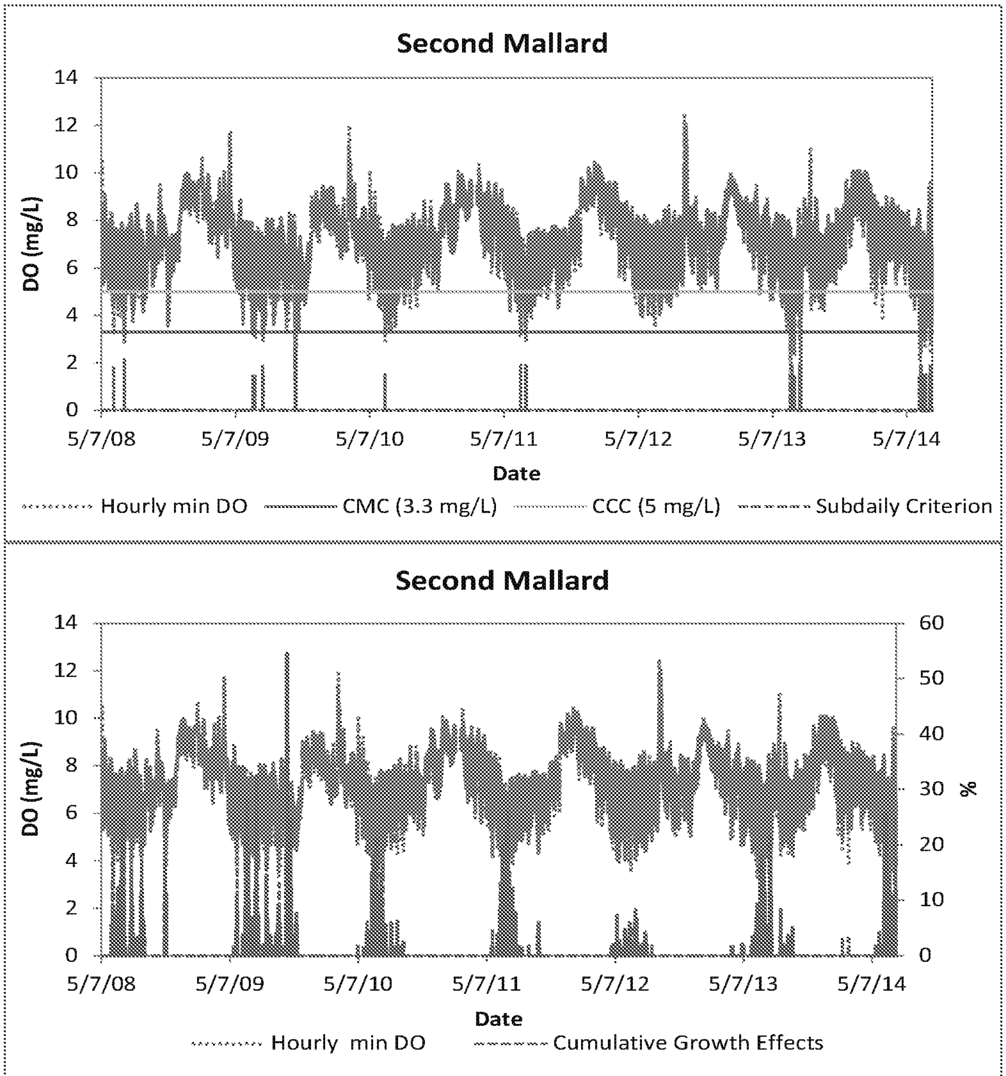


Figure B- 39 Hourly DO concentrations compared to the criterion minimum concentration (CMC) and criterion continuous concentration (CCC) at Second Mallard Slough

The cumulative distributions of 1-hour minimum, 4-hour minimum, 6-hour minimum and 24-hour minimum DO concentrations for First Mallard and Second Mallard Sloughs were estimated to show the frequency of exceedances (Figure B-40, Figure B-42). For 20% of the time, the 24-hour minimum DO is less than 5 mg/L. The 1-hour to 6-hour min DO is generally less than 6 mg/L for 15–25% of the time.

The DO concentrations at First Mallard Slough show seasonal variations, with lower concentrations during summer months when temperatures are higher (Figure B-41). However, the lowest DO occurs during the fall, usually in October and November, when the 24-hour and 30-day running averages can fall below 5 mg/L. Similar patterns were found for the Second Mallard Slough DO concentrations (Figure B-42 and Figure B-43).

The statistics relating to the 1-hour, 4-hour, 6-hour, and 24-hour minimum DO concentrations are shown in Table B-7. The mean values of the 1-hour to 24-hour minimum DO concentrations are generally less than 7 mg/L.

Table B-6
Summary of time below DO criterion for the Second Mallard Slough

	Days below 5 mg/L	Days below 7 mg/L	Number of rolling 3-month median of daily DO below 80% saturation	Persistent Exposure		Episodic Exposure	
				Hours below CMC of 3.3 mg/L*	Hours below CCC of 5 mg/L*	Hours below adjusted CMC (based on hourly duration of exposure)*	Hours with cumulative growth reduction >25%*
Number	5	749	1,368	0	0	24	39
Total Data Points	2,229	2,229	2,229	53,363	53,363	53,363	53,363
Percent	0.22%	33.6%	61.37%	0%	0%	0.04%	0.07%

*EPA, 2000

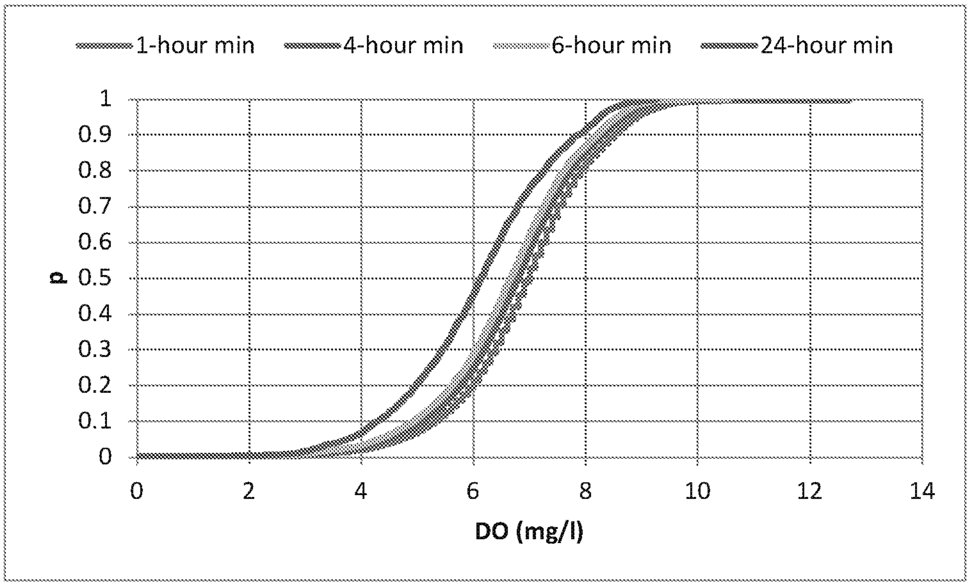


Figure B-40 Cumulative probability (p) distributions of 1-hour min, 4-hour min, 6-hour min, and 24-hour minimum DO concentrations at First Mallard Slough